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THERMAL DUST MEASUREMENTS FROM NUCLEAR DETONATION PHOTOGRAPHY

Information Science, Inc.
123 West Padre Street
Santa Barbara, California 93105

30 November 1978

Final Report for Period 1 May 1978—30 November 1978

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20. ABSTRACT (Continued)

the other major shocks as obtained from measurements of one photographic film of Event CLIMAX. These data should be helpful for future computer code development and validation.

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PREFACE

It is a pleasure to acknowledge the contributions of various individuals from various research organizations. The authors are very grateful to Jerry Carpenter of R&D Associates and Dr. Maxwell Sanford of LASL J-9 for various fruitful discussions and suggestions. Mr. Ed Martin of G.E. TEMPO supplied related information stored in the DNA DASIAC Library. Librarian support at the film archives at Los Alamos Scientific Laboratory and DNA were most useful.

Perhaps the most useful and significant influence on the contents of this report were the group working meetings organized and directed by Dr. George Ullrich of the Defense Nuclear Agency, SPSS Directorate. The authors are most thankful to the members of this group for their contributions.

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1.0 INTRODUCTION

Under certain conditions in nuclear detonation environments a precursor pressure wave is formed, which propagates ahead of the main shock and considerably modifies the intensity of the air blast environment. A better understanding of the precursor environment is required in order to develop credible, predictive models and to assess the impact of precursed airblast environments on targeting and damage predictions.

This study reviews some of the photographic data taken during past nuclear detonations with specific emphasis on dusty, thermal induced, pre-shock environments near the ground surface.

In view of the suspected importance of the dusty pre-shock environment in modifying the airblast environment, measurements have been made to provide some insight as to the origin and mechanism of the formation of a precursor. These measurements define the nature of the dusty environment which, in turn, can cause high non-uniform air temperatures of short durations above the desert surface. In general, a cloud of material forms above the soil surface following intense nuclear thermal irradiation. It is not yet clear whether these cloud puffs are made up of discrete particles or concentrated gaseous or vapor emanations. It is, however, possible to conclude that under certain surface conditions, a layer of very highly heated gaseous mixture forms above the ground surface prior to shock arrival. This layer (which sometimes ignites) can be related to the formation and propagation of the precursor shock wave.

The height observations of the dust/cloud puffs (reported below) are consistent with the few results obtained with fine-wire aspirated thermocouple and resistance thermometer measurements.¹ In general, extremely high temperatures were measured (in some cases, in excess of 1,000° C) in the air just above ground level, up to a height of a few feet. Furthermore, the air temperature varied rapidly with height; above 10 feet, the temperature increase above ambient was relatively small.

In this study, the observed heated layer of air mixture may provide one of the necessary conditions for the development of the precursor wave. Although no definite conclusion is made about the mechanism of formation of the heated layer, it is clear from the presented data that one of the conditions important to the formation of the heated layer of air is the nature and characteristics of the underlying terrain in the vicinity of a nuclear detonation. In view of this observation, dust measurements were also made over a few areas of pre-event stabilized soil.

The report is organized into three sections. The first section deals with a few measurements from Operation BUSTER. It is this operation that yielded a set of films suitable for quantifying thermal layer formation. Studies of some two hundred scientific film records dealing with Events TURK, MET, BEE, PRINCILLA, and TUMBLER 1 through 4, led to inconclusive results.

The second section deals with results from only one film of Event CLIMAX (Operation UPSHOT KNOTHOLE). This event was chosen because films of this event document the evolution of various shock waves -- the normal breakaway fireball shock, the ground reflected shock, the onset of the precursor, as well as other shocks, and the propagation characteristics of these shocks.

The third section presents a summary of part of the extensive data of pre-shock dust that exists in film records from Event ENCORE (Operation UPSHOT KNOTHOLE). This event was instrumented with 193 cameras dispersed about ground zero, and therefore allows detailed measurements over a large, thermally irradiated area of the Frenchman Flat test site.

1.1 SECTION I

During basic thermal radiation measurements of Operation BUSTER (Oct. - Nov. 1951) a photographic program was introduced into the experiment which recorded both thermal and blast effects on idealized forest fuels of the U.S. Forestry Service. An examination of these films revealed that long before the arrival of the shock front, large quantities of smoke or dust rose from the ground in sufficient quantities to interfere seriously with thermal measurements and with photography close to the ground. This is illustrated in PLATE 1 through enlargements of two typical scenes reproduced from the 16 mm motion picture films obtained in this photographic program. Scene A illustrates the pre-shock appearance of the general area around the local station. As shown, the main body of each of these films presents a view of the forest fuel beds of grass, punky wood, pine needles and hardwood leaves. In addition, the scene shows the naturally occurring fuels at the test site -- brush, grass clumps and Joshua trees. Between the Joshua tree and the fuel beds is a dirt road showing loose dirt.

Scene B depicts conditions prior to shock arrival at one location following ground surface irradiation by the detonation of Event BUSTER DOG. The main body of this scene shows a view of the forest fuel beds as presented in Scene A. The section in the upper right hand corner is a view towards ground zero as seen through the small stellite mirror in front of the camera. As shown in this scene a nonuniform layer of gaseous emanations has risen to approximately 12 feet following nuclear thermal irradiation of the original surface area shown in Scene A.

Figure 1.10 presents the originally reported² measured data of thermal dust rise on event BUSTER BAKER (28 Oct. 1951; 3.8 KT; HOB 1118 feet; Yucca area). As indicated, the reported dust layer at a distance of 1890 feet from ground zero reaches a height of 11.5 feet for a total thermal fluence of 38 cal/cm². Similarly, Figure 1.20 presents the originally reported² measured data of thermal dust rise on event BUSTER

CHARLIE (30 Oct. 1951; 13.7 KT; HOB 1132 feet; Yucca test area). The figure reports a dust layer rise to 19.4 feet at a ground station 3810 feet from ground zero, prior to shock arrival. The total thermal fluence at this station was 23 cal/cm^2 . At this time, proper documentation has not been found which describes the method used to arrive at these reported height-versus-time measurements.

The current measurements at two stations for Event CHARLIE are presented in Figure 1.21 through 1.29. For this event, the cameras were mounted three feet above the ground surface and aimed at the fuel cells. Much data was lost due to poor film type selection. Nevertheless, Figures 1.21 and 1.22 summarize the data which could be measured from two films at a station 3,000 feet from ground zero.

As shown in these figures, during the first 1.3 seconds the cloud puffs near the Joshua tree have reached the height of 4 feet. Since the camera characteristics are not documented, camera framing speeds were established by observing the time of shock arrival at the Joshua tree. Likewise, all measurements were made at the Joshua tree, since for this event, its height was recorded³ as 15 feet. This value was used to establish the magnification factor in the plane at the Joshua tree.

Figures 1.23 through 1.28 summarize similar measurements for Event CHARLIE at a ground station 5,000 feet from ground zero. Because of the lower brightness level at this station, data could be measured from six different Kodachrome films. Again, measurements were made near the Joshua tree (at this station, the Joshua tree was 20 feet high) since only there could the magnification factor be established.

During these measurements, smoke was observed to originate from some of the fuel cells and desert brush. During all measurements it could be seen that the entire area (shown in PLATE 1 A) is completely obliterated by pre-shock smoke and dust, exhibiting nonuniform vertical rise and horizontal drift.

Figure 1.29 summarizes the dust height-versus-time for Event BUSTER CHARLIE at this ground station. This curve combines all the data presented from the six cameras in Figures 1.23 through 1.28. As shown, the cloud puffs, or wisps, rise to 7.5 feet prior to shock arrival for the thermal fluence of 14 cal/cm^2 .

It should be noted that in all measurements presented in this report, the height of the dust, or smoke puff, is taken to be a representative point, which is judged to properly represent the average upper edge.

For Event BUSTER DOG (Nov. 1951; 21.2 KT; HOB 1417 feet; Yucca Flat area), photographic data was obtained at two stations -- 5,000 feet and 7,000 feet from ground zero. Since current interest exists at the larger overpressure stations, no measurements of thermal dust were made at the 7,000 foot station.

For this event, the cameras were loaded with black and white film having an exposure latitude of 3,000. Even with this extended range (as compared to color film), some of the data was lost due to overexposure. Thus, time zones void of points in the plotted data (for example, Figure 1.34, first 1.7 seconds) are not shown because the data is lost.

During measurement, it was observed for this event at the 5,000 foot from ground zero station, the tops of desert brush, fuel cell brush (No. 79), as well as Joshua tree bark, were on fire at 0.35 seconds. At 1.8 seconds, all fuel cells (73 through 79 -- Plate 1 A) are totally covered by smoke, dust, or gaseous emanations. It is this gaseous mixture that was measured near the Joshua tree from each film taken by the six cameras. The results of these measurements are presented in Figures 1.30 through 1.35. Figure 1.36 reproduces the average values of these measurements as presented in these six figures. As seen in this figure, the gaseous, thermally-induced puffs reach a height of 13.3 feet before shock arrival. For completeness, Figure 1.37 presents a measure of the thermal energy deposited at this station, as a function of time. The topmost curve (#1) is the actual data for this station, while the center curve (#2) represents the percentage of total energy deposited.



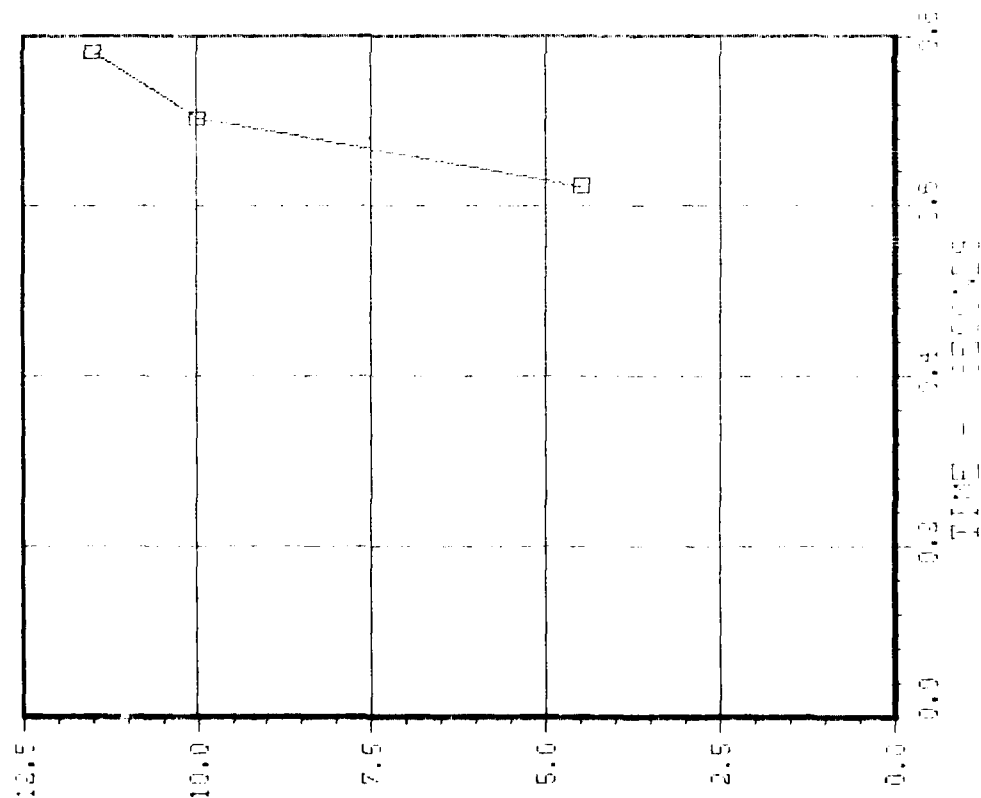
A.



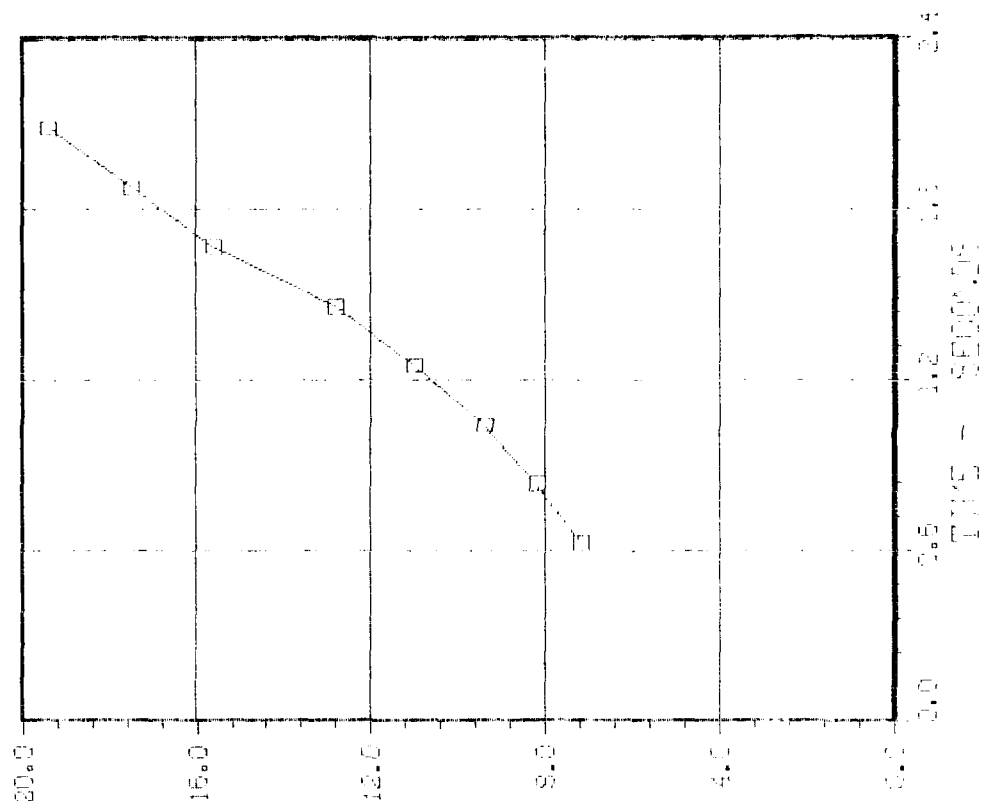
B.

Plate 1. Event BUSTER DOG.

DUST RISE - EVENT 88.0R
 FIGURE 1.10 FILM 9999
 DISTANCE FROM GROUND ZERO 1890 FEET
 SHOCK ARRIVAL TIME 1.13 SECONDS
 PEAK PRESSURE 7.50 PSI
 THERMAL ENERGY 33 CAL/CM² +-2



DUST RISE - EVENT 88.0R
 FIGURE 1.09 FILM 9999
 DISTANCE FROM GROUND ZERO 3810 FEET
 SHOCK ARRIVAL TIME 2.17 SECONDS
 PEAK PRESSURE 4.40 PSI
 THERMAL ENERGY 33 CAL/CM² +-2



HEIGHT - FEET

DUST RISE - EVENT CHARLIE

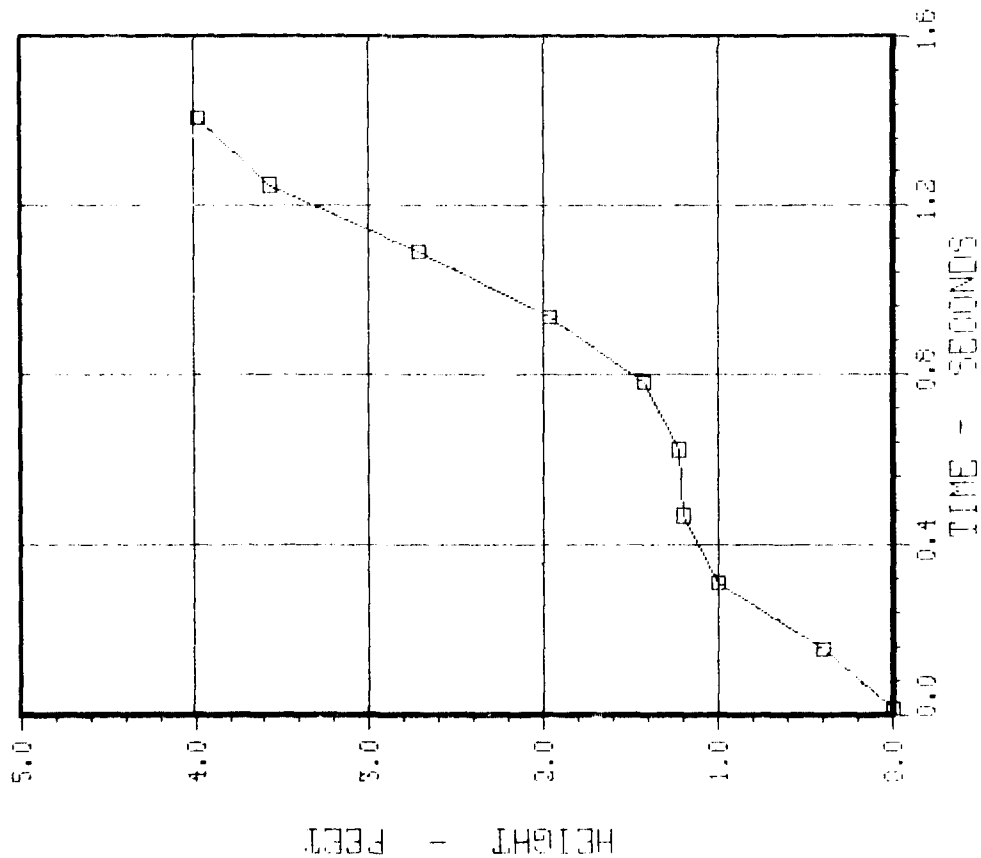
FIGURE 1.21 FILM 4

DISTANCE FROM GROUND ZERO 3000 FEET

SHOCK ARRIVAL TIME 1.77 SECONDS

PEAK PRESSURE 6.50 PSI

THERMAL ENERGY 37 CAL/CM²→2



DUST RISE - EVENT CHARLIE

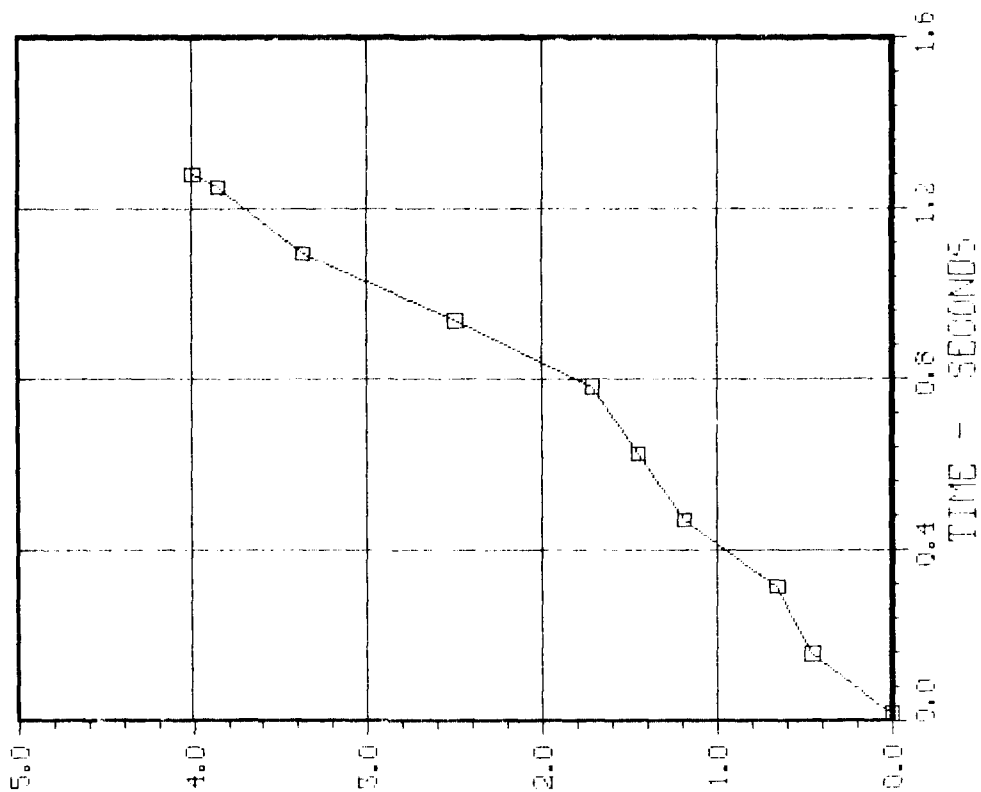
FIGURE 1.22 FILM 5

DISTANCE FROM GROUND ZERO 3000 FEET

SHOCK ARRIVAL TIME 1.77 SECONDS

PEAK PRESSURE 6.50 PSI

THERMAL ENERGY 37 CAL/CM²→2



DUST RISE - EVENT CHARLIE

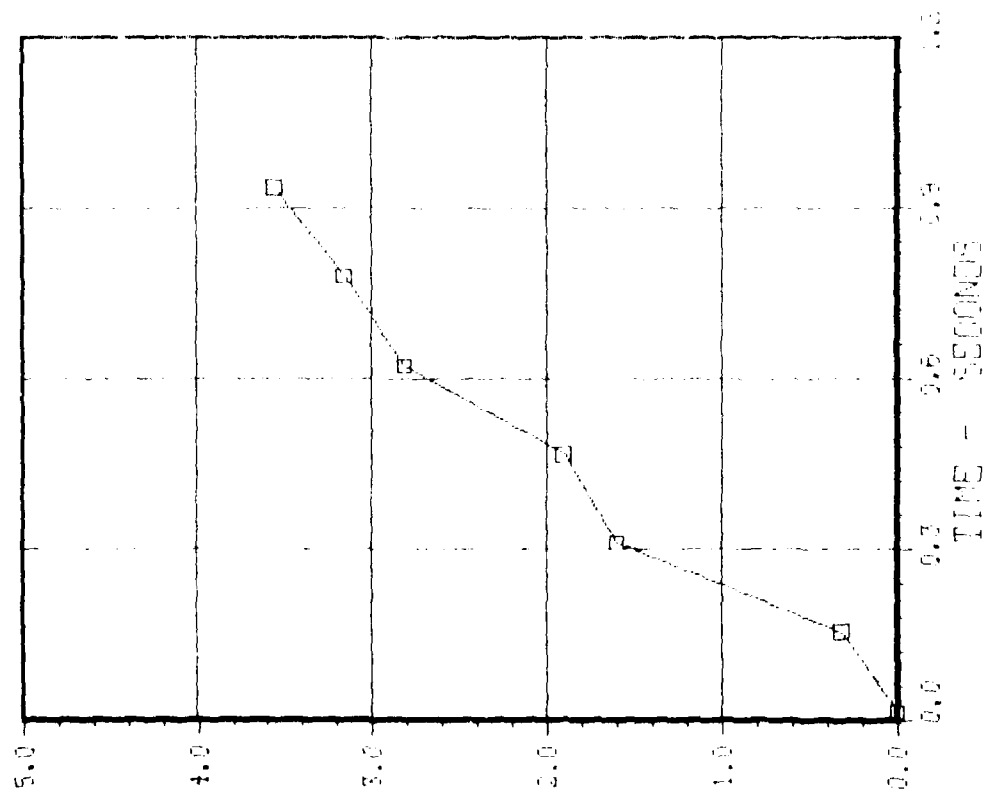
FIGURE 1.23 FILM 1

DISTANCE FROM GROUND ZERO 5000 FEET

SHOCK ARRIVAL TIME 3.14 SECONDS

PEAK PRESSURE 3.90 PSI

THERMAL ENERGY 14.90/CM²



DUST RISE - EVENT CHARLIE

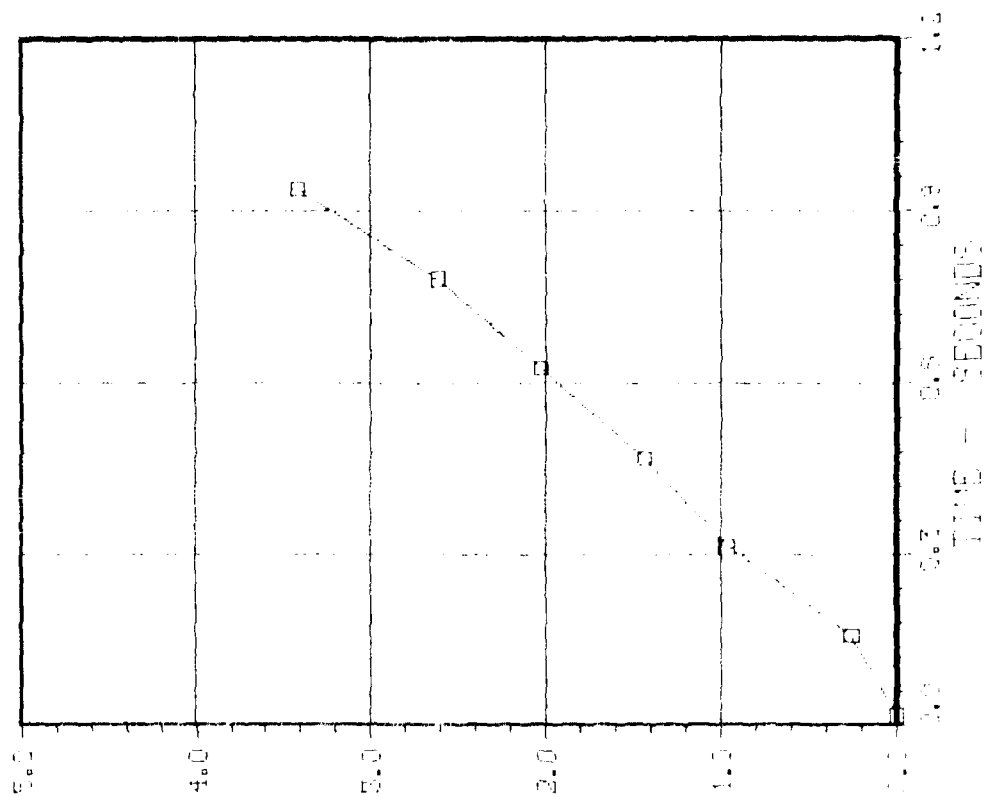
FIGURE 1.24 FILM 2

DISTANCE FROM GROUND ZERO 5000 FEET

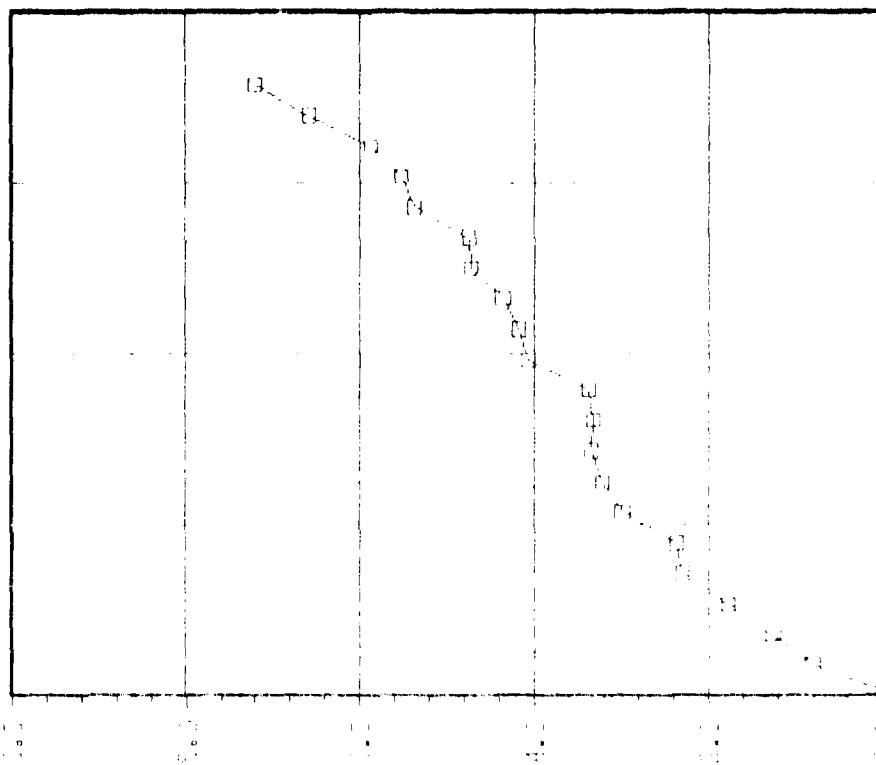
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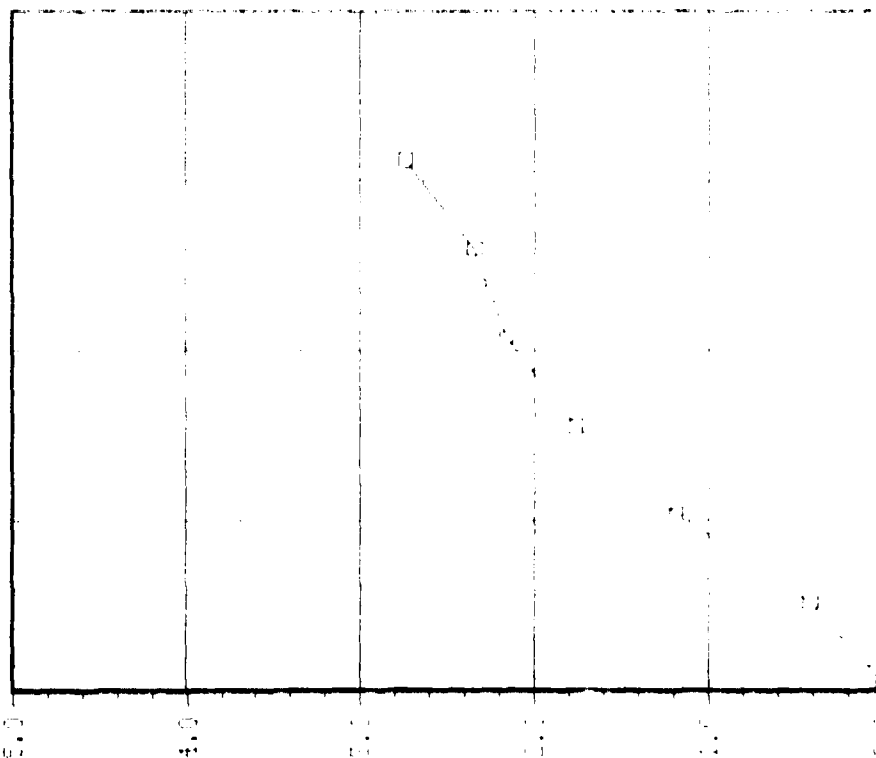
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THERMAL ENERGY 14.90/CM²



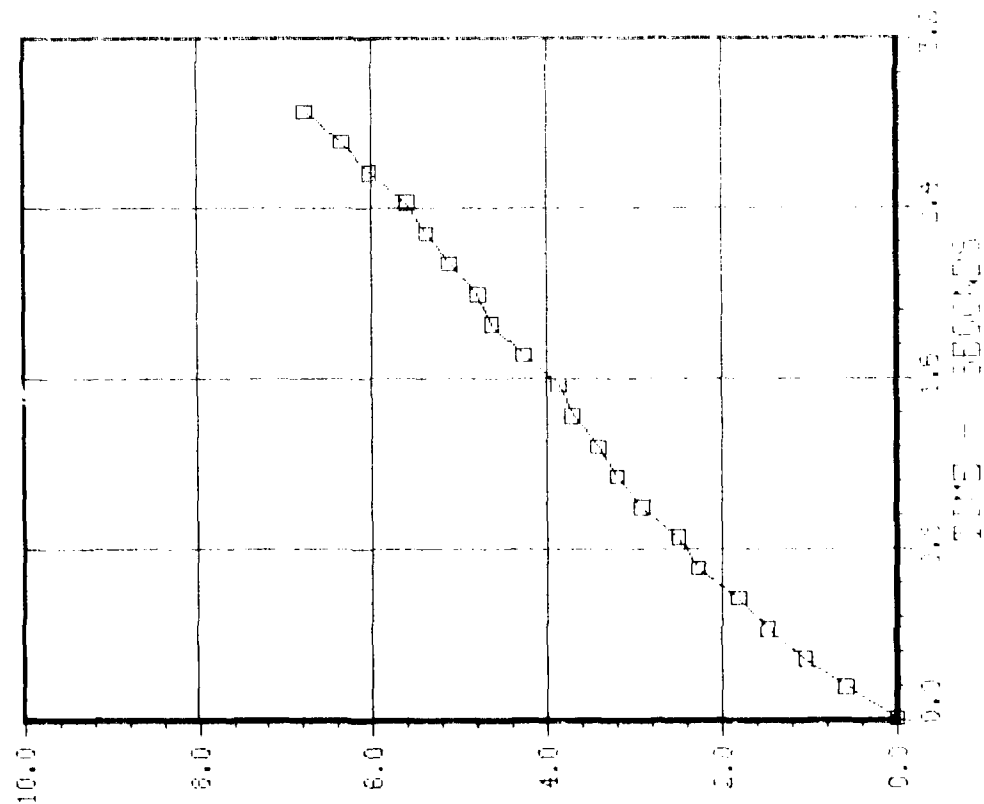
HEIGHT - FEET



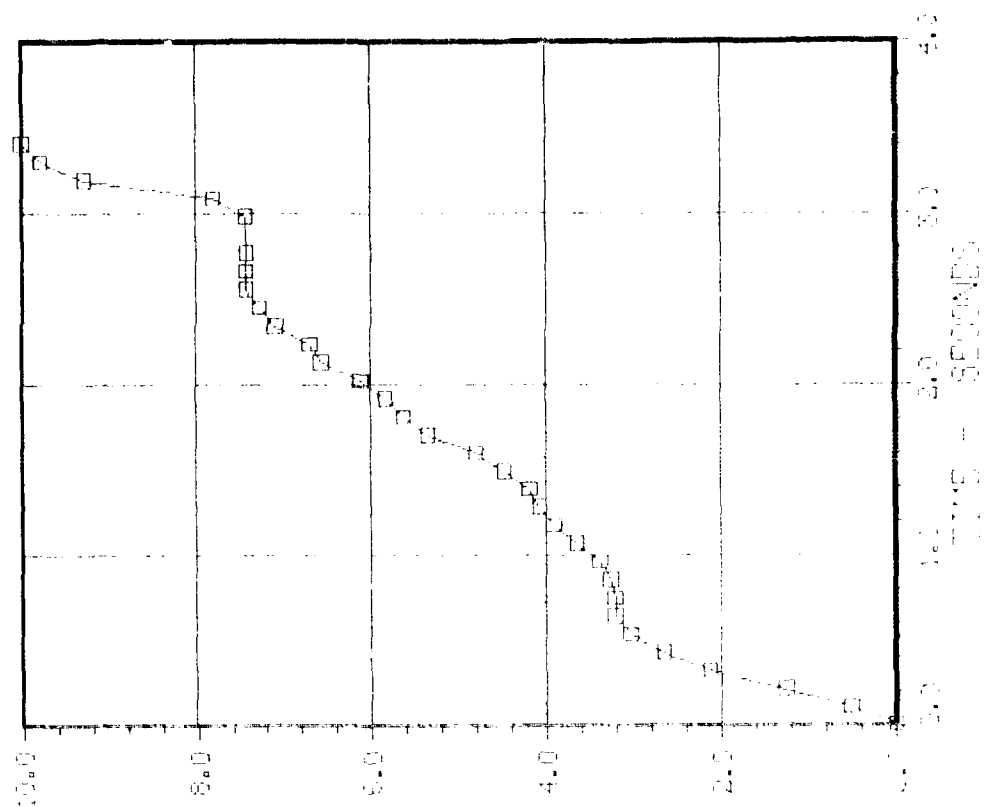


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DUST RISE - EVENT CHARLIE
 FIGURE 1.27 FILM 5
 DISTANCE FROM GROUND ZERO 5000 FEET
 SHOCK ARRIVAL TIME 3.14 SECONDS
 PEAK PRESSURE 3.50 PSI
 THERMAL ENERGY 14 ORU/ICM1--2

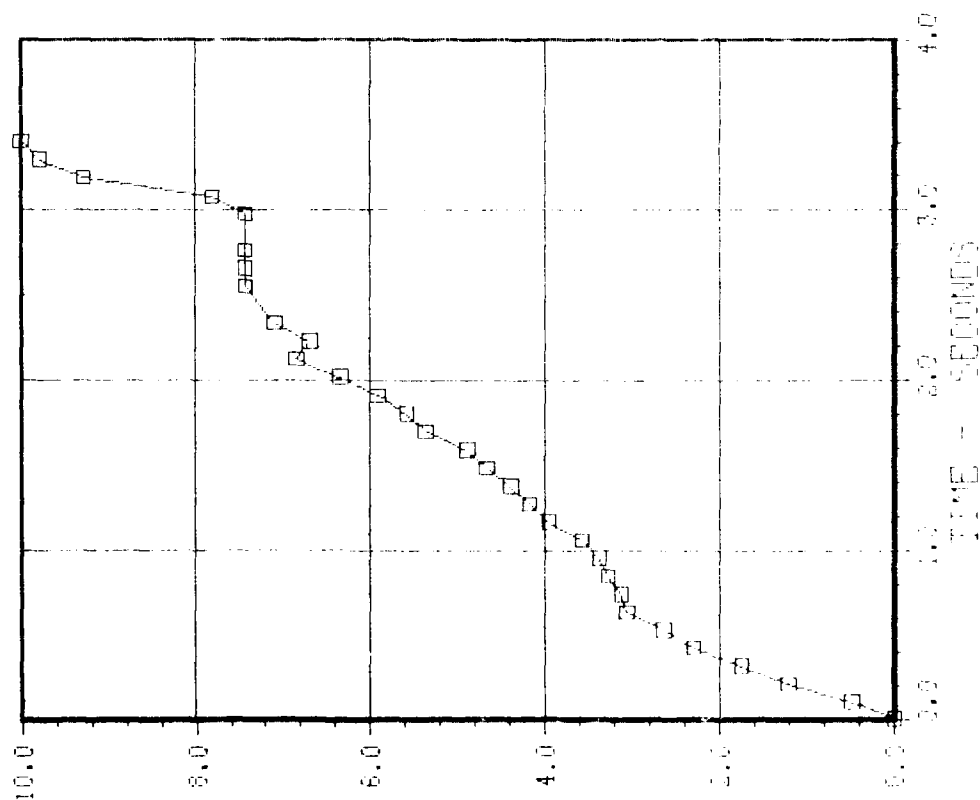


DUST RISE - EVENT CHARLIE
 FIGURE 1.28 FILM 5
 DISTANCE FROM GROUND ZERO 5000 FEET
 SHOCK ARRIVAL TIME 3.14 SECONDS
 PEAK PRESSURE 3.50 PSI
 THERMAL ENERGY 14 ORU/ICM1--2

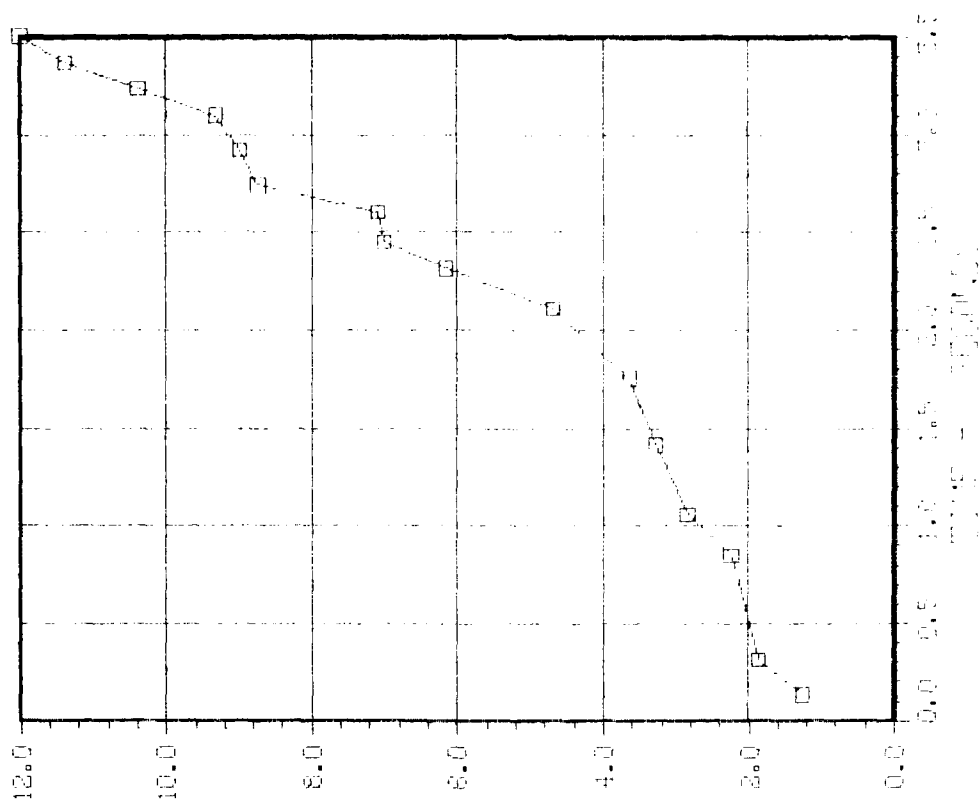


HEIGHT - FEET

DUST RISE - EVENT CHARLIE
 FIGURE 1.29 FILM 123456
 DISTANCE FROM GROUND ZERO 5000 FEET
 SHOCK ARRIVAL TIME 3.14 SECONDS
 PEAK PRESSURE 3.50 PSI
 THERMAL ENERGY 14 CAL/1CM) *2

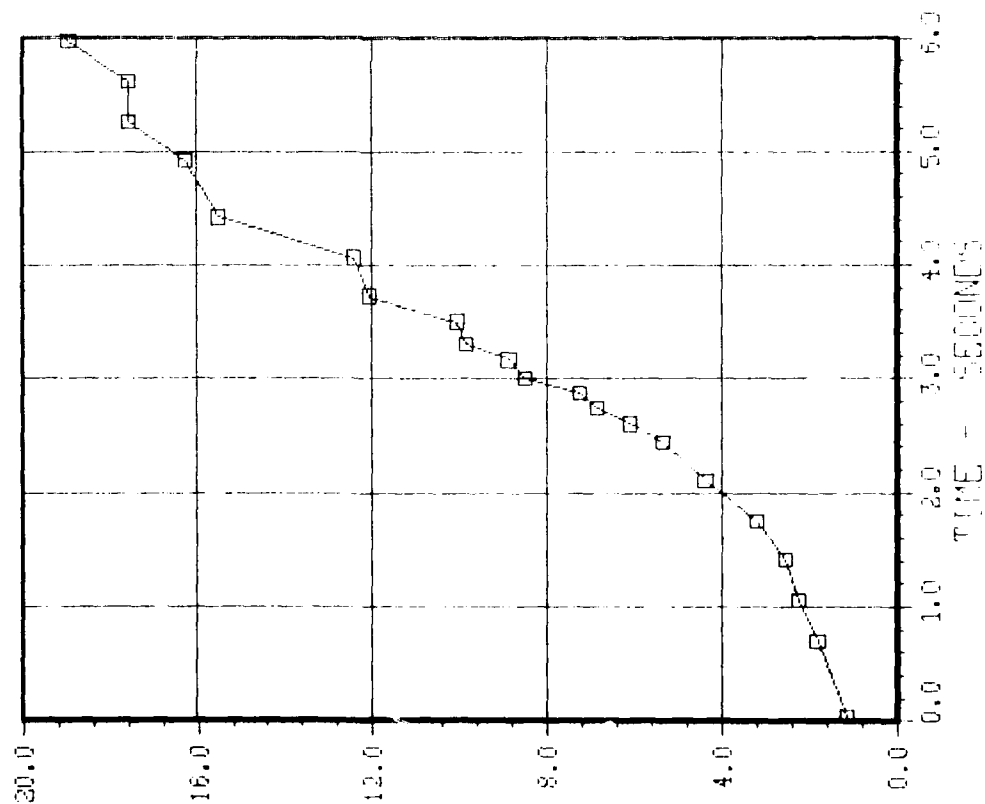


DUST RISE - EVENT DOG
 FIGURE 1.30 FILM 1
 DISTANCE FROM GROUND ZERO 5000 FEET
 SHOCK ARRIVAL TIME 2.92 SECONDS
 PEAK PRESSURE 4.50 PSI
 THERMAL ENERGY 16 CAL/1CM) *2

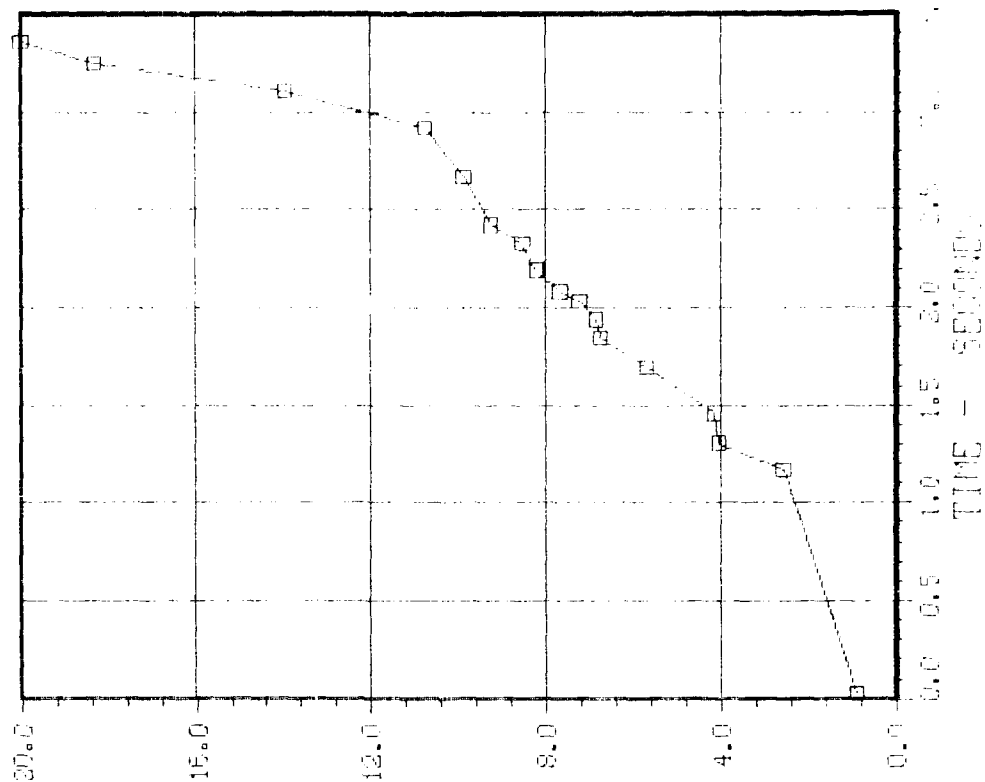


HEIGHT - FEET

DUST RISE - EVENT 008
 FIGURE 1.31 FILM 2
 DISTANCE FROM GROUND ZERO 5000 FEET
 SHOCK ARRIVAL TIME 2.92 SECONDS
 PEAK PRESSURE 4.50 PSI
 THERMAL ENERGY 18 CAL/CM² → 2



DUST RISE - EVENT 009
 FIGURE 1.32 FILM 3
 DISTANCE FROM GROUND ZERO 5000 FEET
 SHOCK ARRIVAL TIME 3.92 SECONDS
 PEAK PRESSURE 4.50 PSI
 THERMAL ENERGY 18 CAL/CM² → 2



HEIGHT - FEET

DUST RISE - EVENT 006

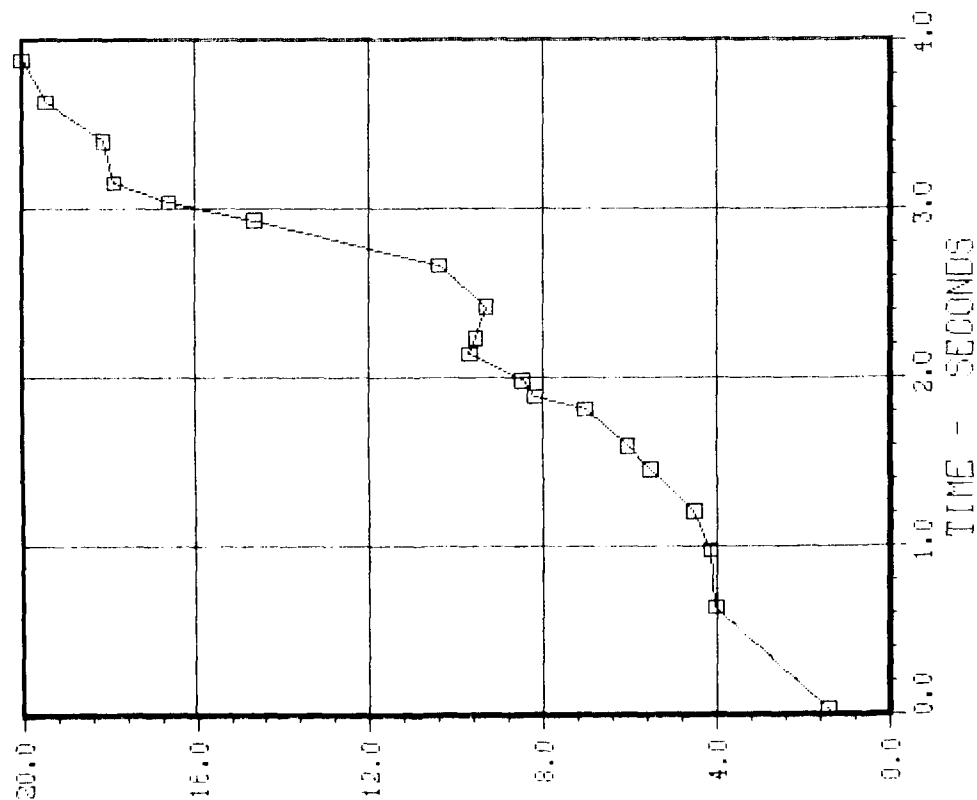
FIGURE 1.33 FILM 4

DISTANCE FROM GROUND ZERO 5000 FEET

SHOCK ARRIVAL TIME 2.92 SECONDS

PEAK PRESSURE 4.50 PSI

THERMAL ENERGY 18 CAL/(CM)²



DUST RISE - EVENT 006

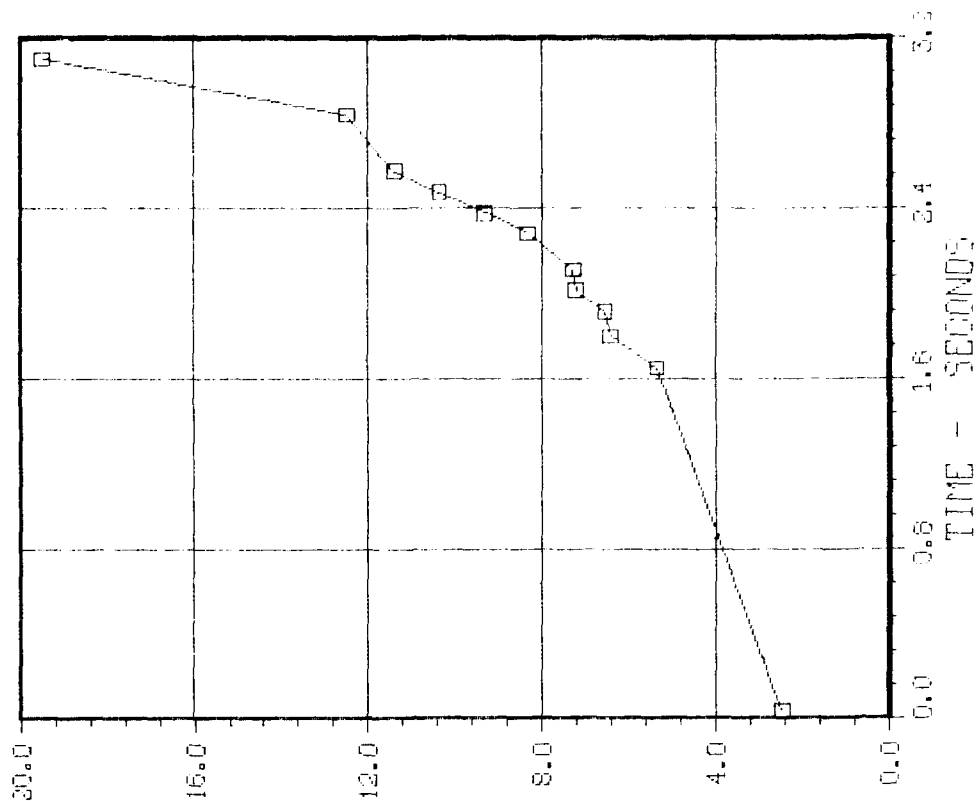
FIGURE 1.34 FILM 5

DISTANCE FROM GROUND ZERO 5000 FEET

SHOCK ARRIVAL TIME 2.92 SECONDS

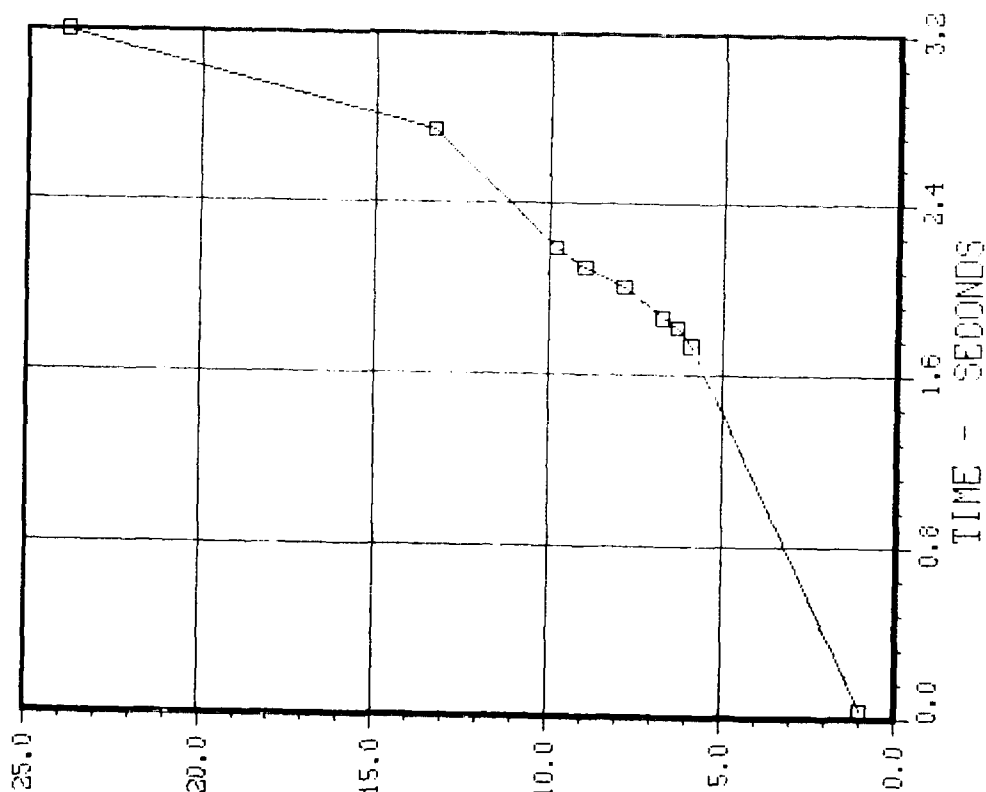
PEAK PRESSURE 4.50 PSI

THERMAL ENERGY 18 CAL/(CM)²

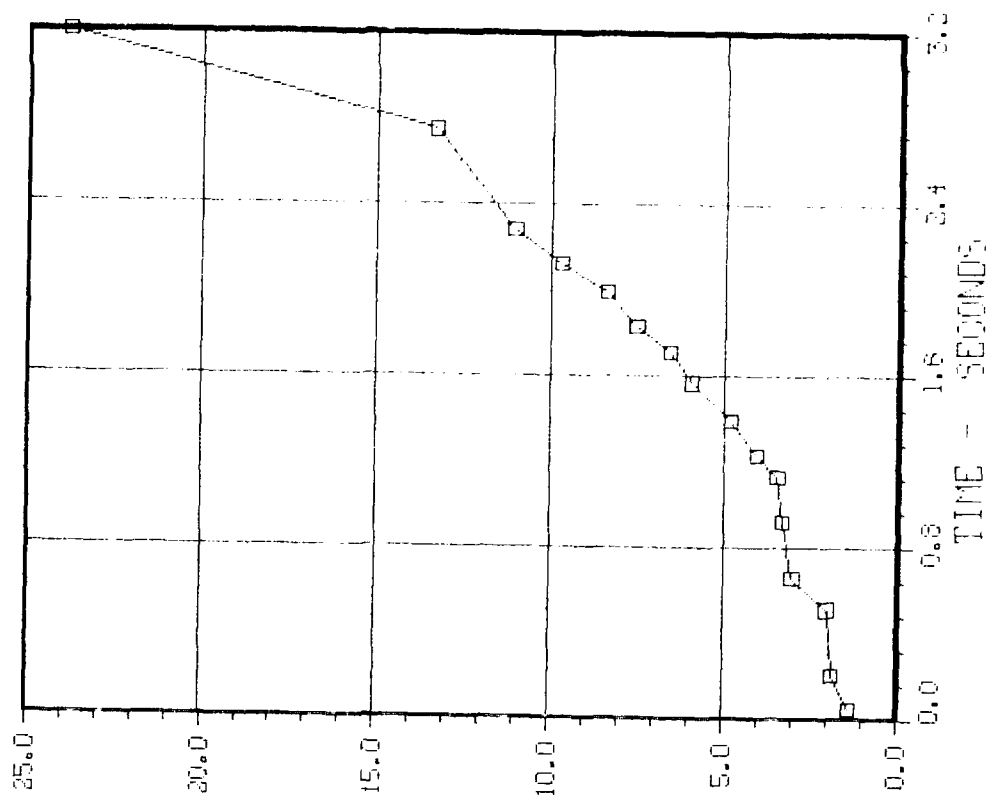


HEIGHT - FEET

DUST RISE - EVENT DOG
 FIGURE 1.35 FILM B
 DISTANCE FROM GROUND ZERO 5000 FEET
 SHOCK ARRIVAL TIME 2.92 SECONDS
 PEAK PRESSURE 4.50 PSI
 THERMAL ENERGY 18 CAL/(CM)**2



DUST RISE - EVENT DOG
 FIGURE 1.36 FILM 123456
 DISTANCE FROM GROUND ZERO 5000 FEET
 SHOCK ARRIVAL TIME 2.92 SECONDS
 PEAK PRESSURE 4.50 PSI
 THERMAL ENERGY 18 CAL/(CM)**2



HEIGHT - FEET

ENERGY DEPOSITED

EVENT 006 - BUSTER SERIES

- 1 -- STATION 3 (5000 FEET) (1)
TOTAL THERMAL 17.5 CAL/CM**2
- 2 -- Percent of Total Energy Deposited
- 3 -- STATION 4 (7000 FEET) (3)
TOTAL THERMAL 11.8 CAL/CM**2

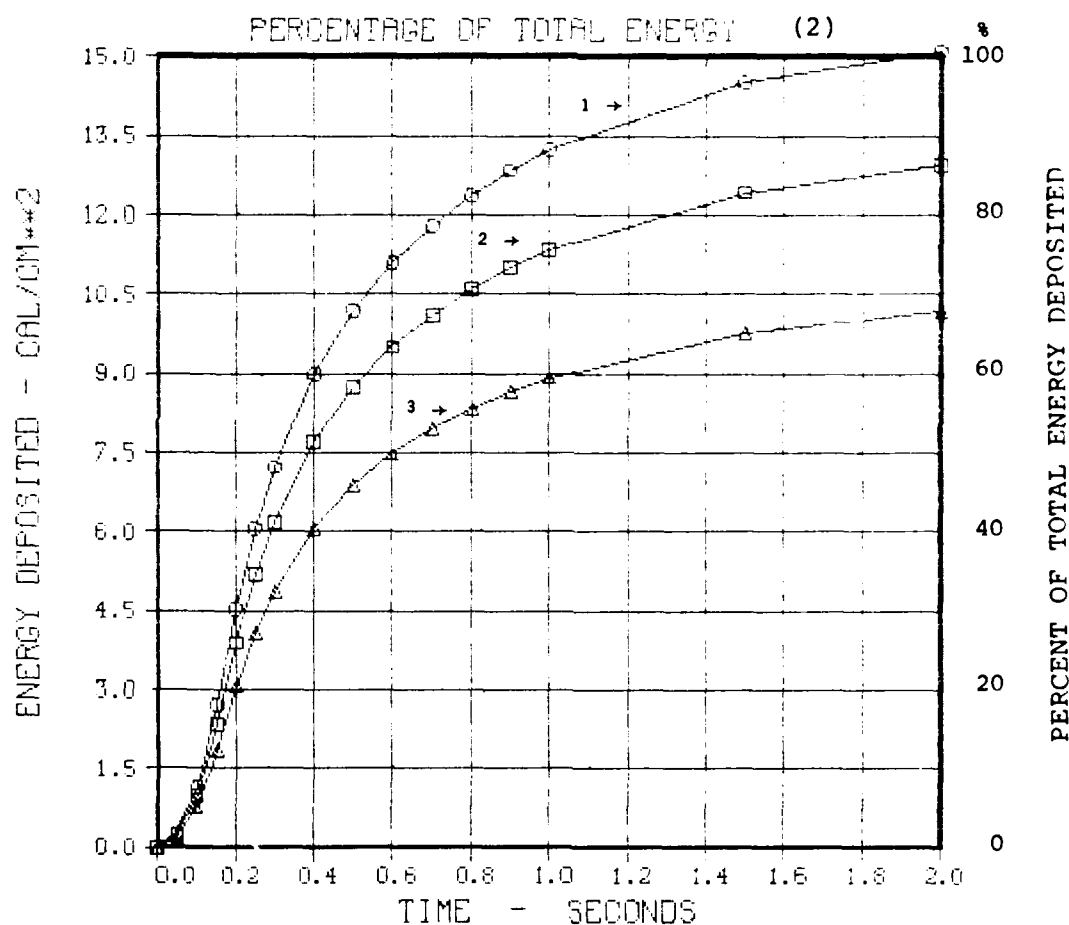


FIGURE 1.37

SECTION II

This section introduces shock propagation data which has been recorded on film through the large change in the index of refraction that is caused by the pressure edge of the propagating shock wave. Although many such shock edges can be observed, this section will deal only with the very early time-varying position of the fireball breakaway shock, the reflected ground shock, and the main precursor shock. Plate 2 illustrates these three shock waves for UPSHOT KNOTHOLE Event CLIMAX (June 1953; 60.8 KT; HOB 1334 feet; near Yucca test area). For this event, the blast line was void of any vegetation and fine silt, as characteristic of the Frenchman Flat area. A strong precursor was developed, which improved the time period of good film recording.

Plate 2 A shows the breakaway shock just at ground strike (0.23 seconds); B shows at 0.3 seconds the original breakaway shock, the reflected shock and the onset of the precursor; C illustrates all three shocks at 0.42 seconds, with the leading edge of the ground-reflected shock becoming luminous just prior to fireball re-entry; D illustrates the ground-reflected shock within the fireball and, faintly, the precursor shock at 0.6 seconds.

The dust data presented in this section is from a film obtained by a 152 mm focal length camera located at a camera station 14,200 feet from ground zero. The film (Plate 2), which can be used very accurately for establishing the onset of the precursor wave and the time-position relationship of the various shocks, is not the most appropriate one for measuring dust rise. For various reasons, such a film format yields very coarse height-of-dust measurements. Since no other more appropriate film exists for this event, it is used for the dust measurements presented in Figures 2.00 through 2.07. The figures represent data at various positions (121 to 1,586 feet) from ground zero. As indicated by the measured points, the thermally-induced dust rises from 2 to 9 feet prior to shock arrival.

The shock arrival times of the various shocks at and near the ground

surface are presented in Figures 2.10 through 2.23. Figures 2.10, 2.11 and 2.12 present the position of the breakaway and ground-reflected shocks. No evidence is found of the formation of a precursor prior to 0.272 seconds. The onset of a third shock which becomes the main precursor shock is first noticed at 0.283 seconds (at film framing speeds of 100 frames/second) at this station. This is shown in Figure 2.13. As illustrated in Figures 2.14 through 2.17, this shock takes a more definite form and begins to extend its lead (hence its arrival time) along the ground over the main fire-ball breakaway shock. The initial observed height varies from 6 to 10 feet. The remaining figures present with increasing time, the initial history of the relative positions of the various shocks with respect to each other.

From Figure 2.21, it is determined that at 0.474 seconds the precursor at ground level is 1558 feet from ground zero. This is in excellent agreement (shock arrival time 0.470 seconds at 1552 foot station) with the earliest SRI measurement⁴. Because of this agreement and the fact that Figures 2.11 through 2.23 extend the currently known shock arrival data for this event toward ground zero, the new data on shock arrival is also presented in Table 2.1. Also included is the SRI shock arrival data from DASA 1200.

For convenience, the radial position (in feet) of the breakaway shock (up to 0.6 seconds) as measured from the burst altitude can be determined from the expression⁵:

$$\log R = a(\log t)^2 + b(\log t) + c$$

$$\text{where } a = 0.02866; b = 0.4944 \text{ and } c = 3.4330$$

In the time region of interest, this expression can be simplified by setting $a = 0$. Under this condition, the expression

$$R = 2710 t^{.49}$$

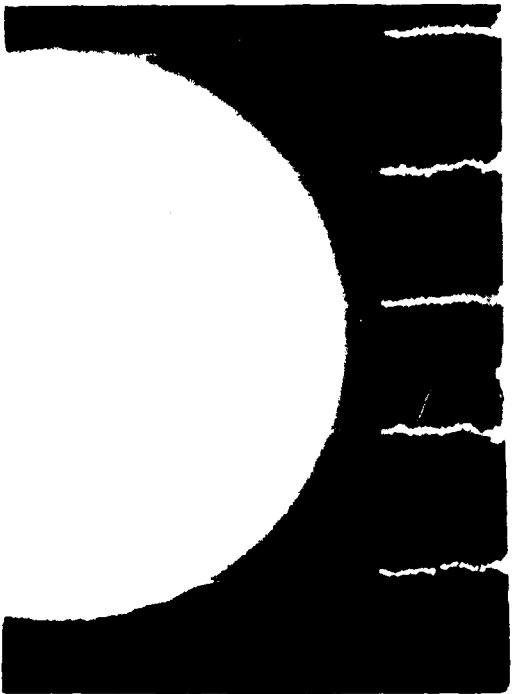
represents the radius of the experimentally determined breakaway shock quite accurately (error of 0.1%).

A word of caution concerning the dust measurements on CLIMAX. As

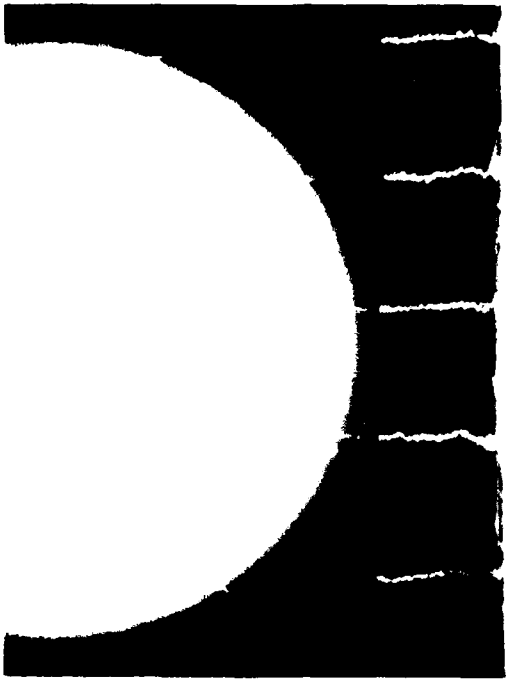
noted, these measurements were made from one film (ideal for shock measurement) obtained with a 152 mm focal length lens from a station 14,200 feet from ground zero. The distance of this station precludes accurate dust measurements. Although a high speed microdensitometer was used, this method was not successful, possibly because of the scanning speed that was employed. Since Event ENCORE (SECTION III) would allow easier, more reliable measurements, only a few dust measurements were made (within ± 1 foot accuracy) on Event CLIMAX. The purpose of presenting this rough CLIMAX data is to show that cloud puffs could be observed on this event at the indicated distances from ground zero, prior to shock arrival. These distances are along the blast line, which was cleared of any vegetation and fine silt.

TABLE 2.1
SURFACE SHOCK ARRIVAL TIME

ISI MEASUREMENTS		SRI MEASUREMENTS ⁴	
Horizontal Distance from GZ (feet)	Time Seconds	Horizontal Distance from GZ (feet)	Time Seconds
0	0.234	1552	0.470
560	0.283	2011	0.621
700	0.293	2485	0.849
766	0.303	2967	1.155
809	0.313	3946	1.830
864	0.323	4438	2.177
921	0.333	4932	2.537
983	0.343	5428	2.896
1050	0.353	6420	3.642
1082	0.363	7415	4.416
1137	0.373	8411	5.204
1186	0.383	9906	6.414
1235	0.393	11403	7.644
1286	0.404	13400	9.304
1326	0.414		
1362	0.424		
1416	0.434		
1445	0.444		
1484	0.454		
1558	0.474		
1622	0.494		
1727	0.525		



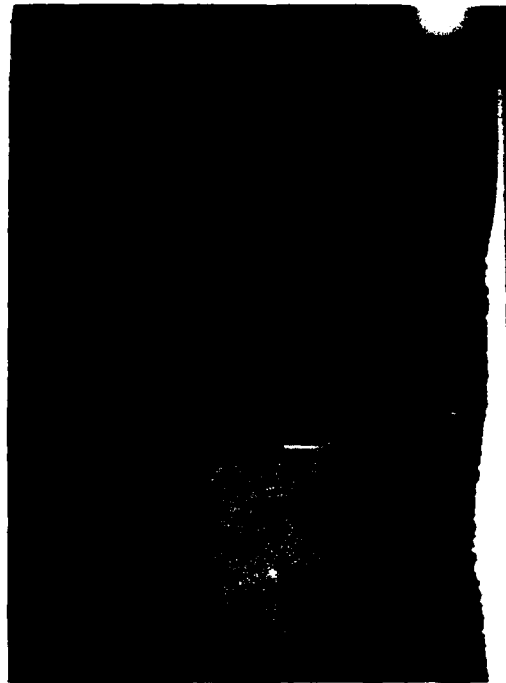
A. FILM 171092-Frame 22



B. FILM 171092-Frame 30



C. FILM 171092-Frame 42



D. FILM 171093-Frame 60

Plate 2. Shock.

DUST RISE - EVENT CLIMAX

FIGURE 2.00 FILM 171082

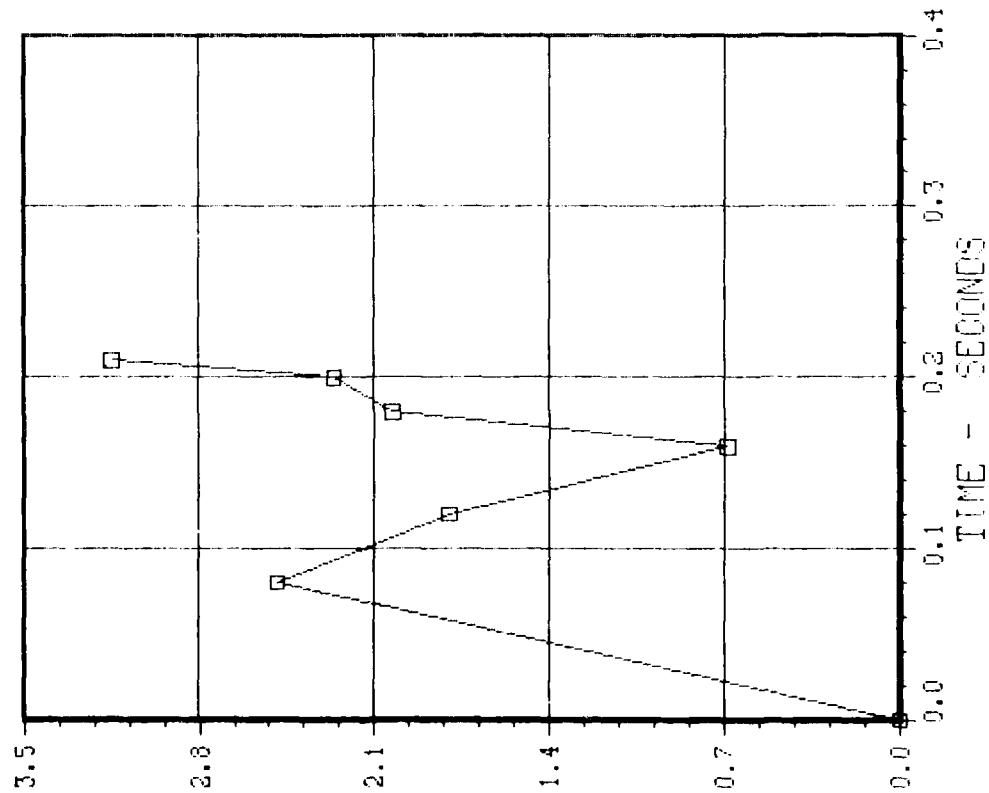
DISTANCE FROM GROUND ZERO 121 FEET

SHOCK ARRIVAL TIME 0.23 SECONDS

PEAK PRESSURE PSI

THERMAL ENERGY

CAL/(CM)**2



DUST RISE - EVENT CLIMAX

FIGURE 2.01 FILM 171082

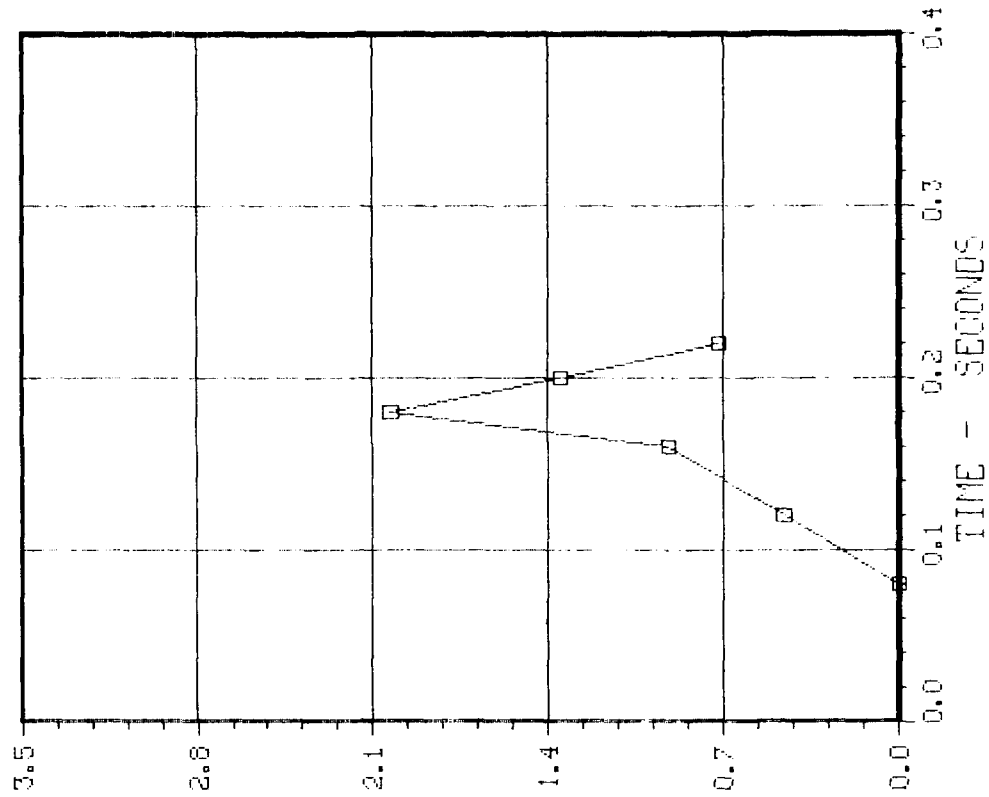
DISTANCE FROM GROUND ZERO 274 FEET

SHOCK ARRIVAL TIME 0.24 SECONDS

PEAK PRESSURE PSI

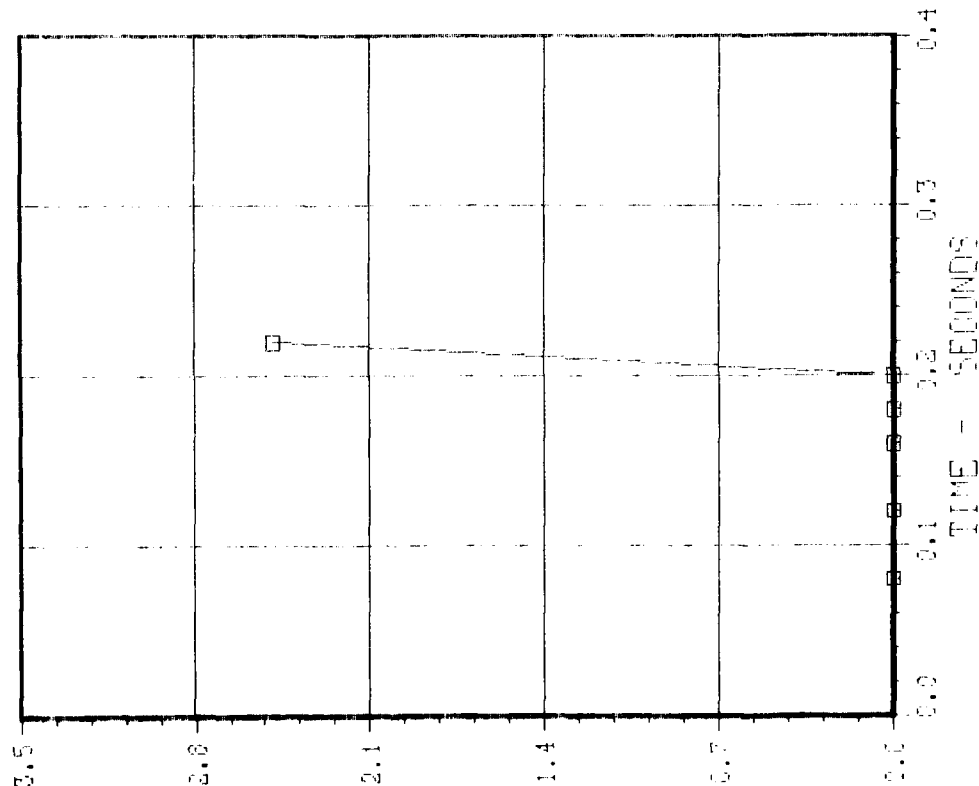
THERMAL ENERGY

CAL/(CM)**2

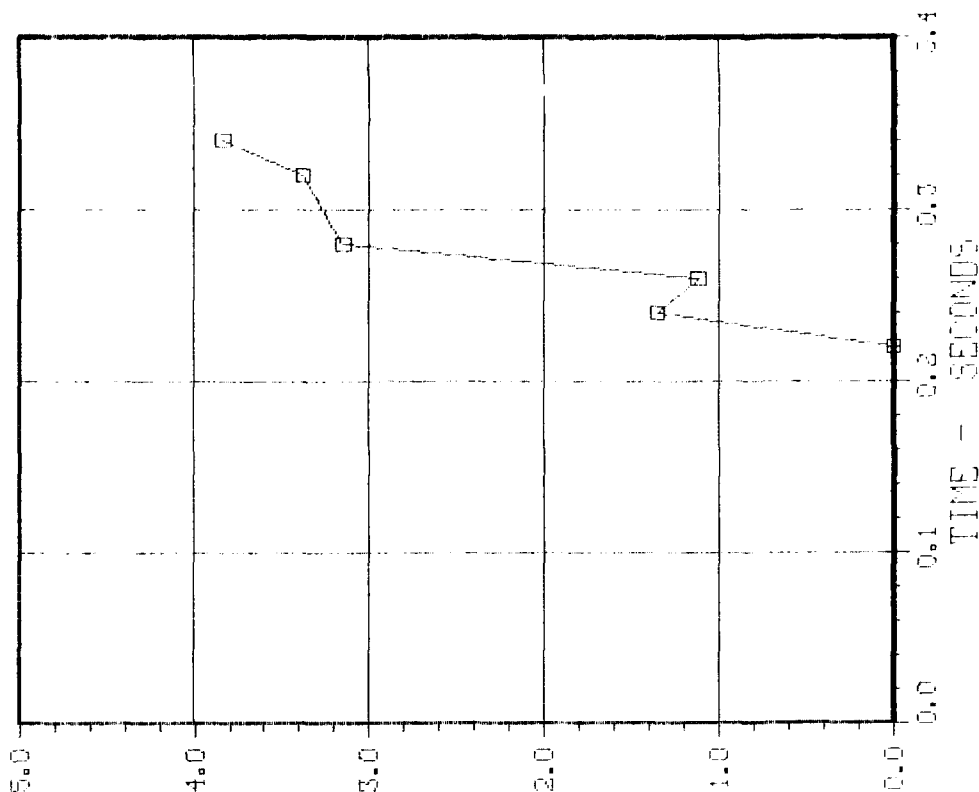


HEIGHT - FEET

DUST RISE - EVENT CLIMAX
 FIGURE 3.02 FILM 171082
 DISTANCE FROM GROUND ZERO 495 FEET
 SHOCK ARRIVAL TIME 0.32 SECONDS
 PEAK PRESSURE PSI
 THERMAL ENERGY CAL/(CM)² 2



DUST RISE - EVENT CLIMAX
 FIGURE 2.03 FILM 171082
 DISTANCE FROM GROUND ZERO 929 FEET
 SHOCK ARRIVAL TIME 0.36 SECONDS
 PEAK PRESSURE PSI
 THERMAL ENERGY CAL/(CM)² 3



DUST RISE - EVENT CLIMAX

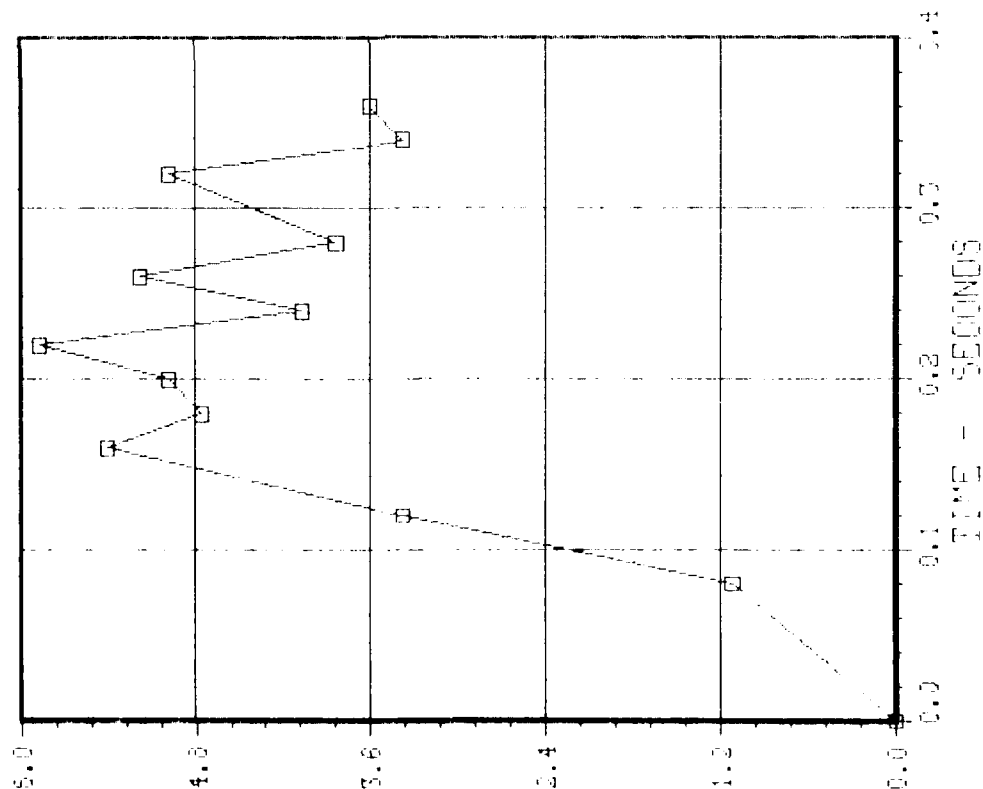
FIGURE 2.04 FILM 171082

DISTANCE FROM GROUND ZERO 1063 FEET

SHOCK ARRIVAL TIME 0.36 SECONDS

PEAK PRESSURE PSI

THERMAL ENERGY CAL/(CM)²



HEIGHT - FEET

DUST RISE - EVENT CLIMAX

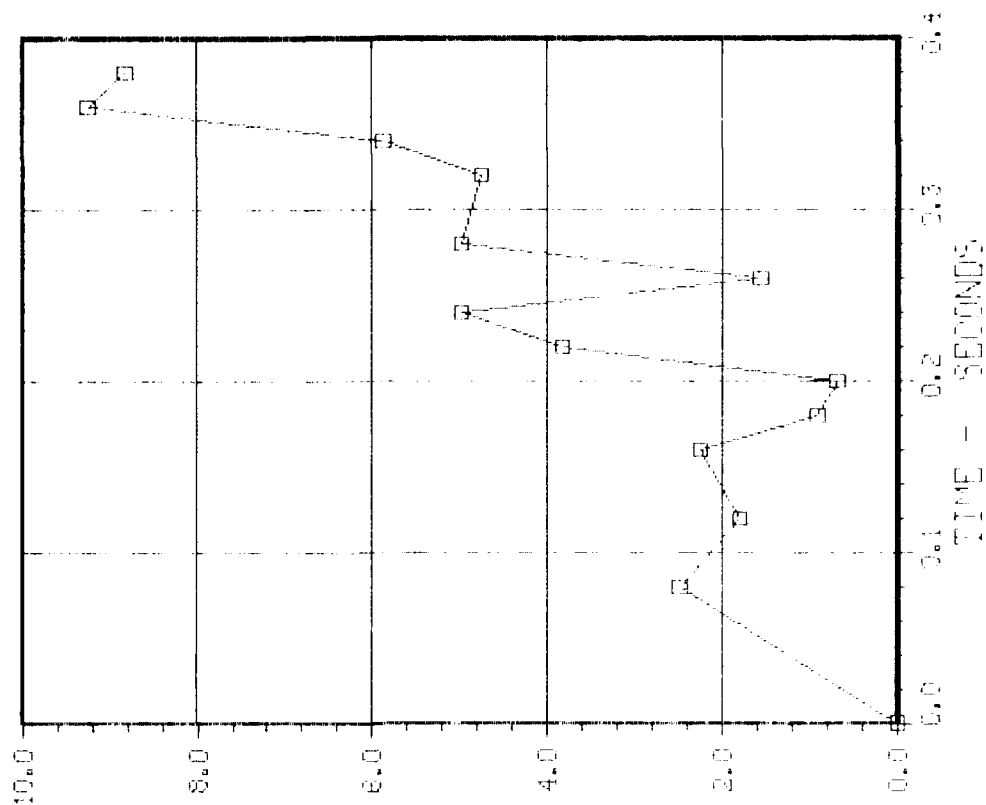
FIGURE 2.05 FILM 171082

DISTANCE FROM GROUND ZERO 1289 FEET

SHOCK ARRIVAL TIME 0.39 SECONDS

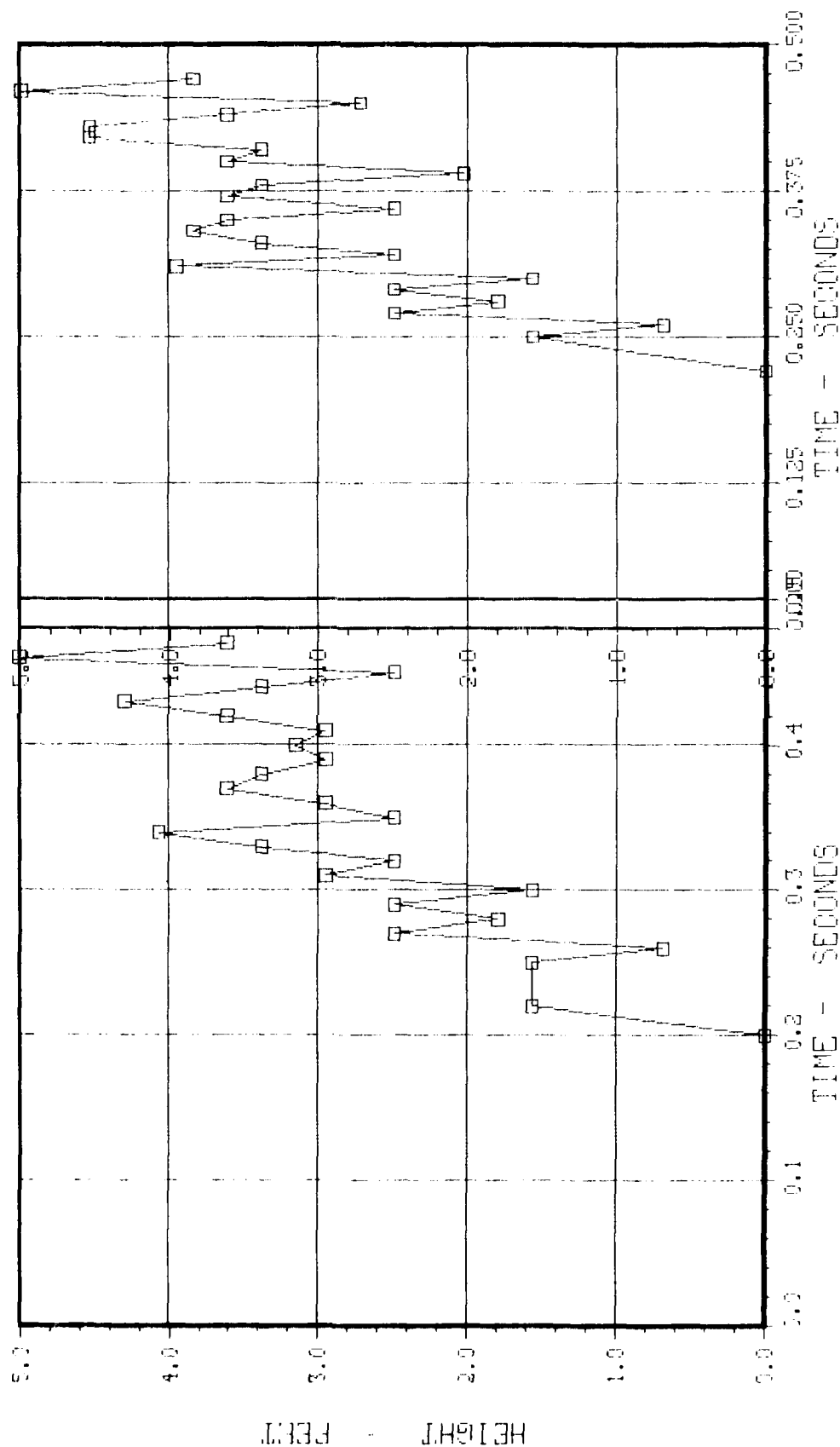
PEAK PRESSURE PSI

THERMAL ENERGY CAL/(CM)²



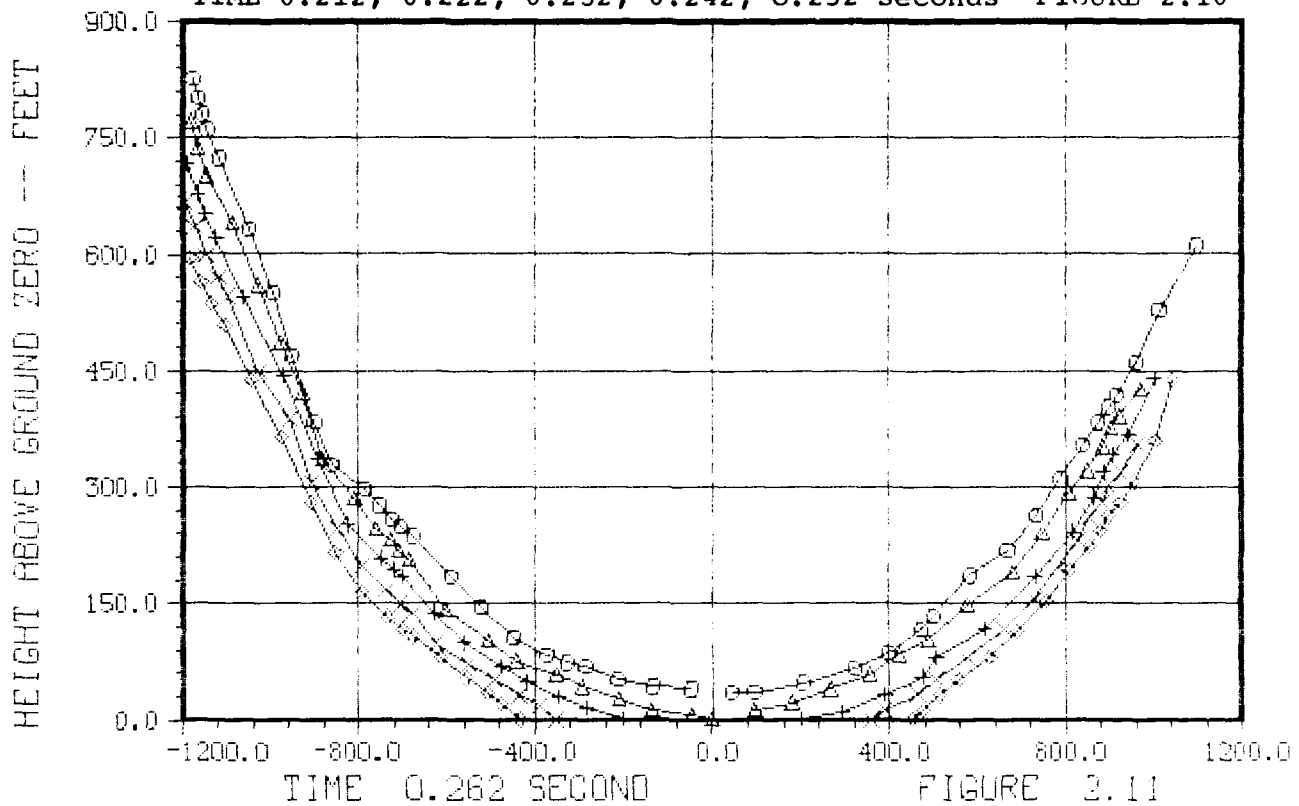
DUST RISE - EVENT CLIMAX
 FIGURE 2.06 FILM 171082
 DISTANCE FROM GROUND ZERO 1540 FEET
 SHOCK ARRIVAL TIME 0.47 SECONDS
 PEAK PRESSURE 43.5 PSI
 THERMAL ENERGY CAL/(CM)**2

DUST RISE - EVENT CLIMAX
 FIGURE 2.07 FILM 171082
 DISTANCE FROM GROUND ZERO 1588 FEET
 SHOCK ARRIVAL TIME 0.47 SECONDS
 PEAK PRESSURE 38.0 PSI
 THERMAL ENERGY CAL/(CM)**2



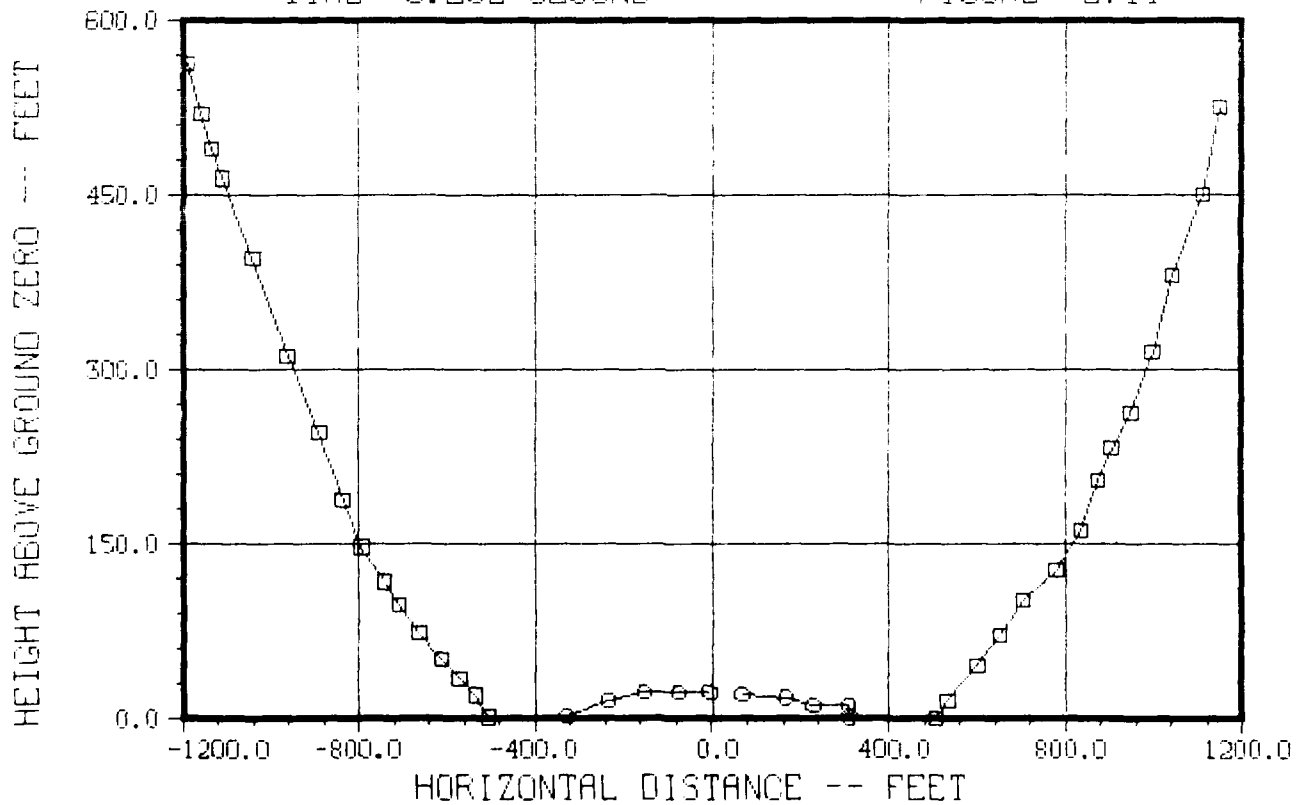
SHOCK PROPAGATION BREAKAWAY AND REFLECTED SHOCKS

TIME 0.212, 0.222, 0.232, 0.242, 0.252 seconds FIGURE 2.10



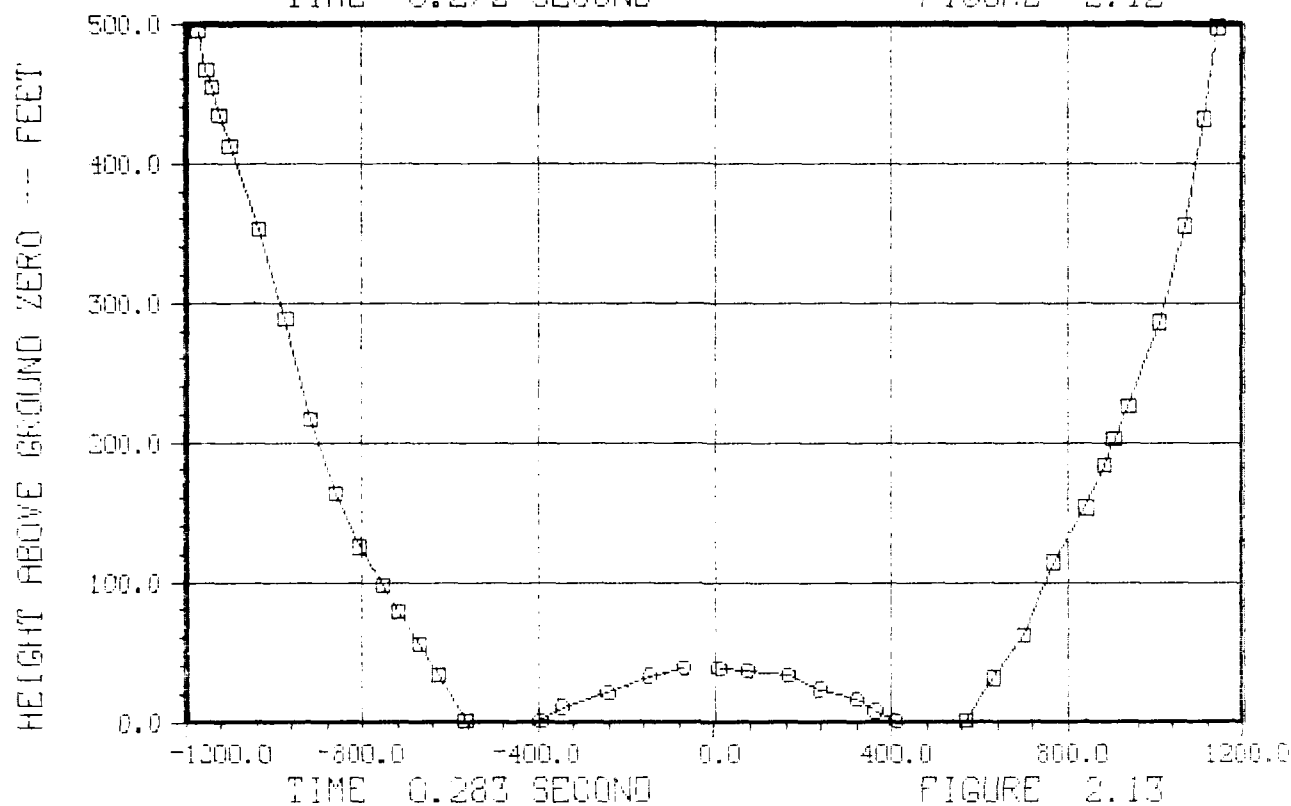
TIME 0.262 SECOND

FIGURE 2.11



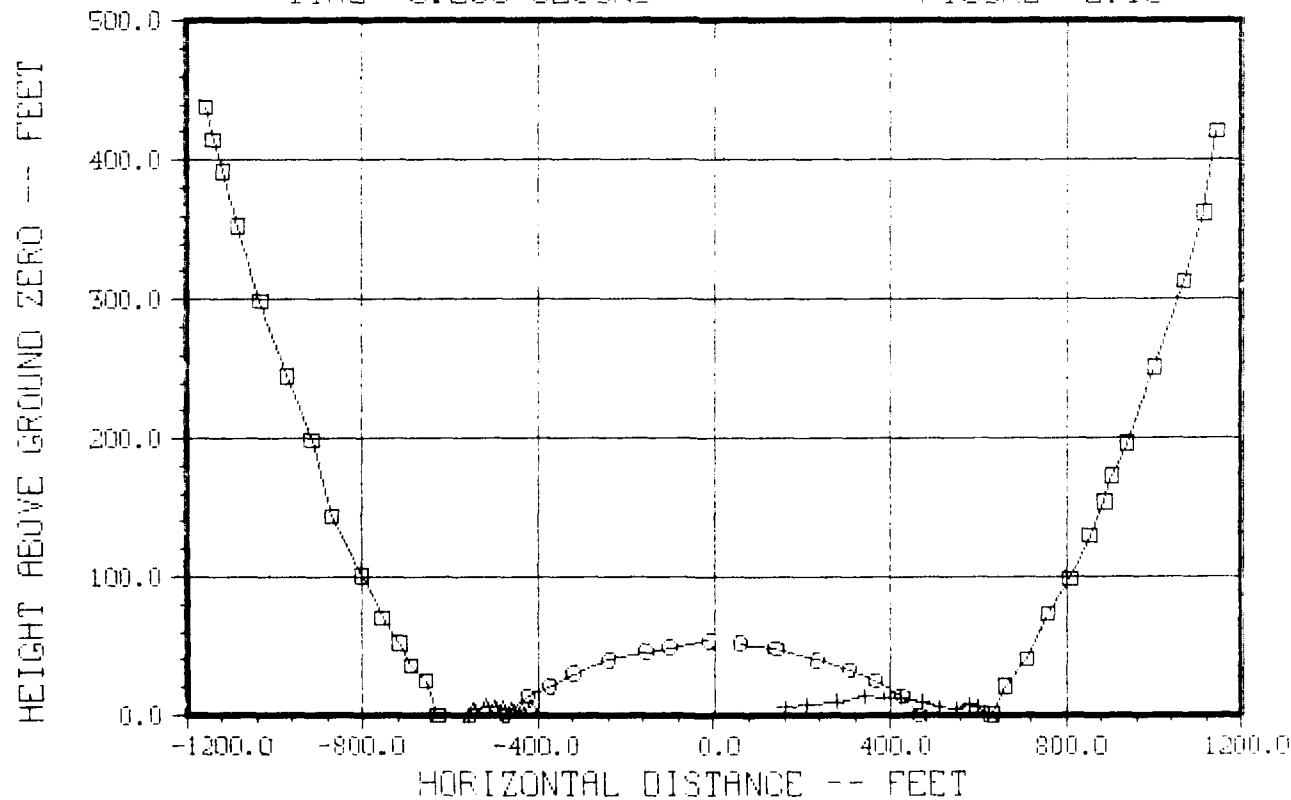
SHOCK PROPAGATION
 BREAKAWAY, REFLECTED AND PRECURSOR SHOCKS
 TIME 0.272 SECOND

FIGURE 2.12

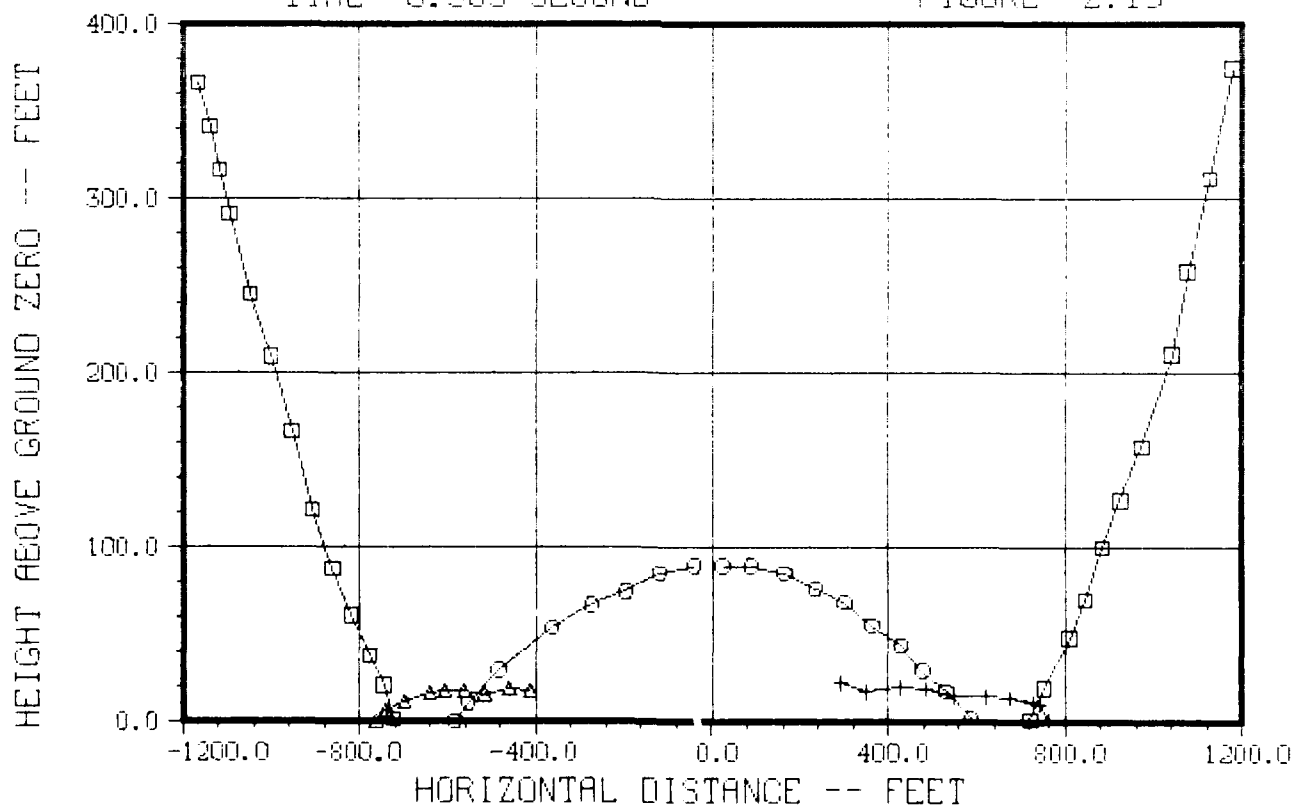
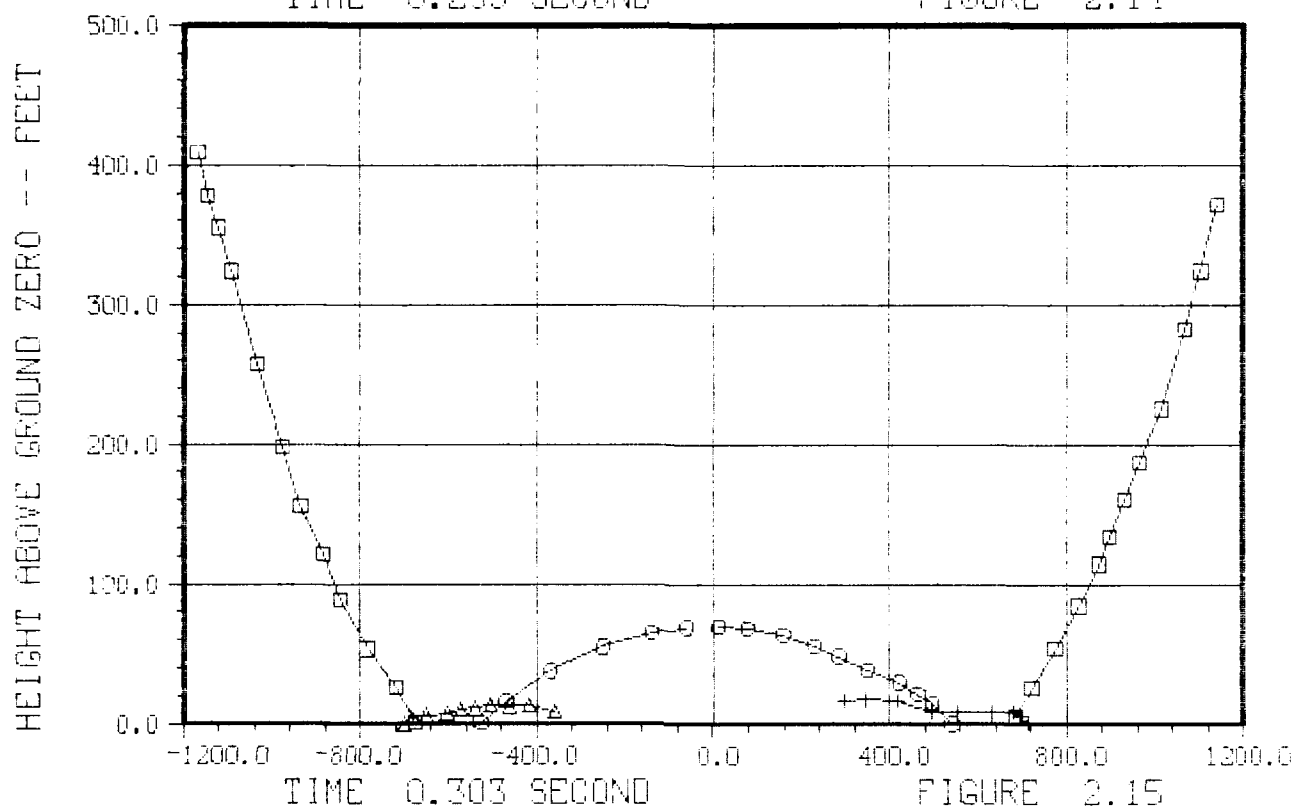


TIME 0.283 SECOND

FIGURE 2.13

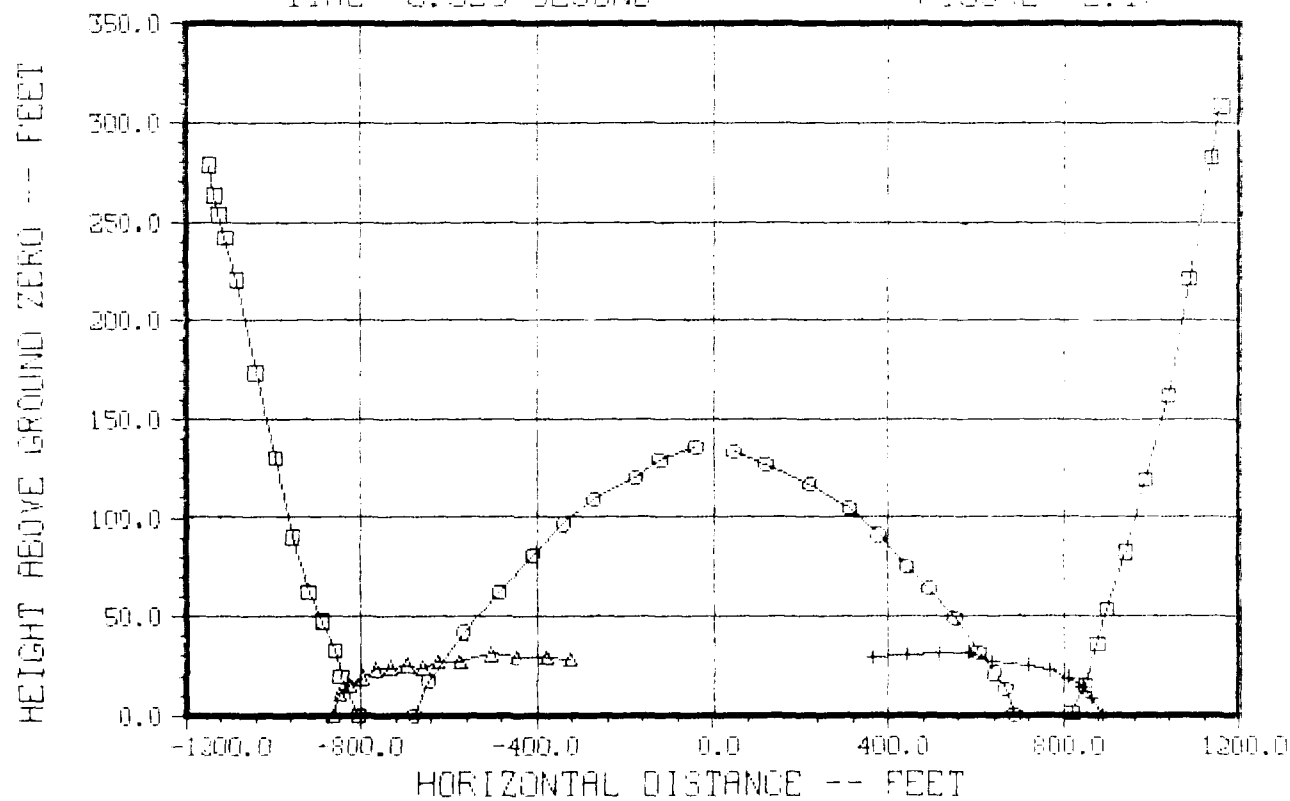
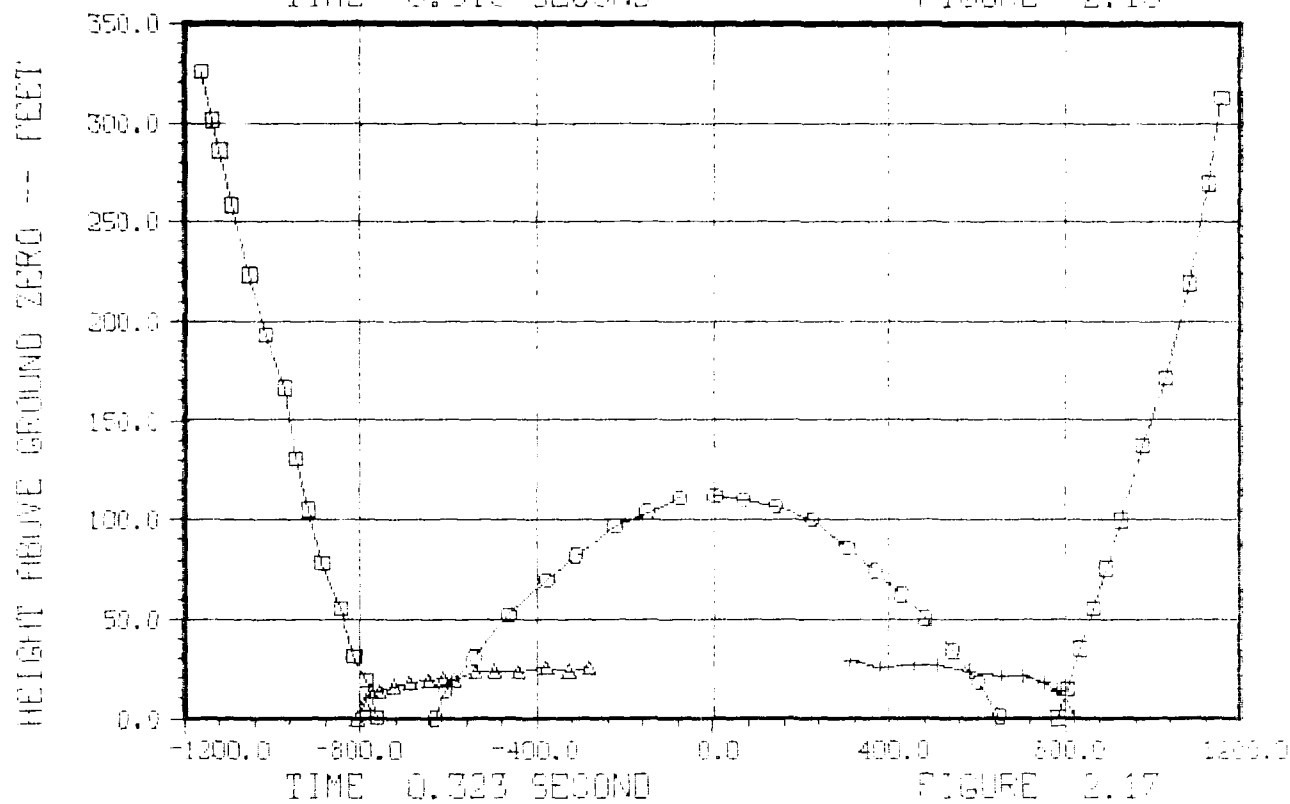


SHOCK PROPAGATION
BREAKAWAY, REFLECTED AND PRECURSOR SHOCKS
TIME 0.293 SECOND FIGURE 2.14



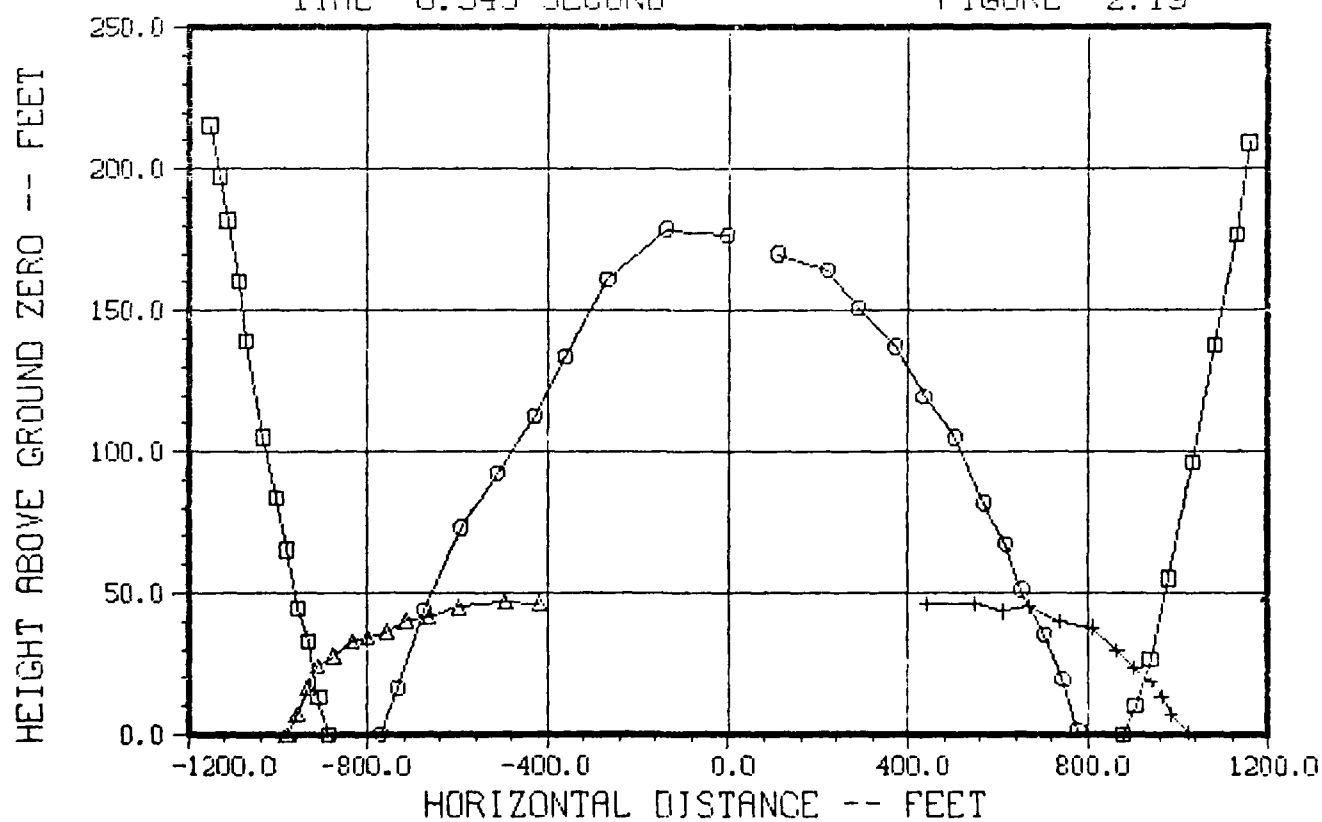
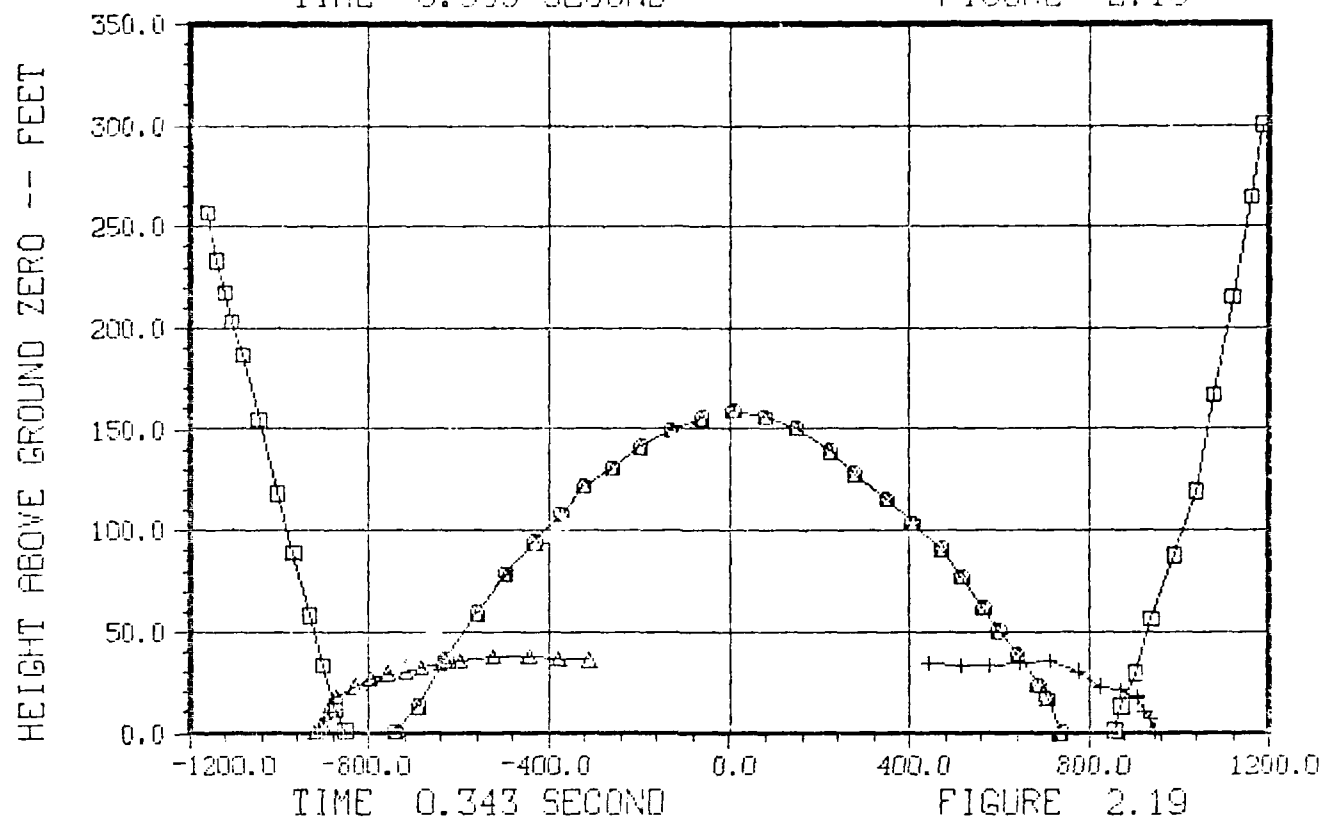
SHOCK PROPAGATION
BREAKAWAY, REFLECTED AND PRECURSOR SHOCKS
TIME 0.313 SECOND

FIGURE 2.15



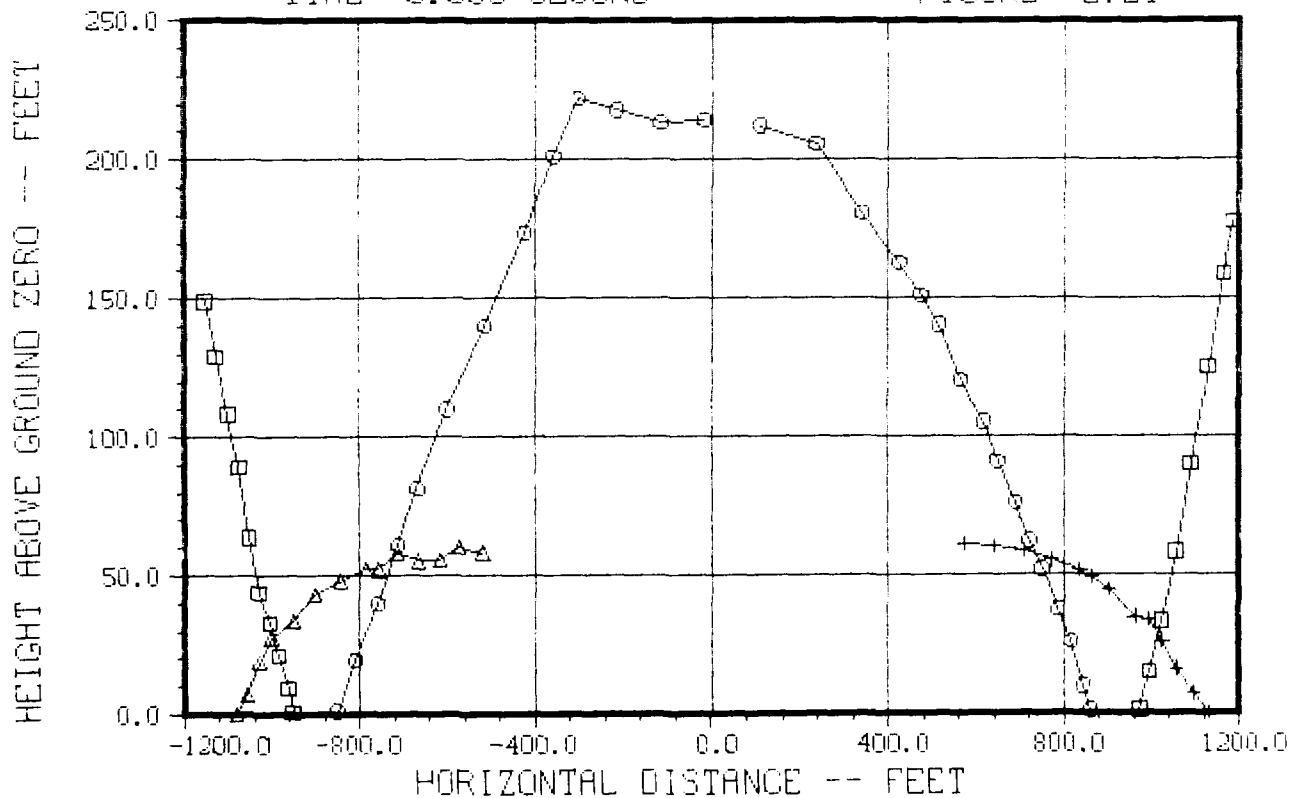
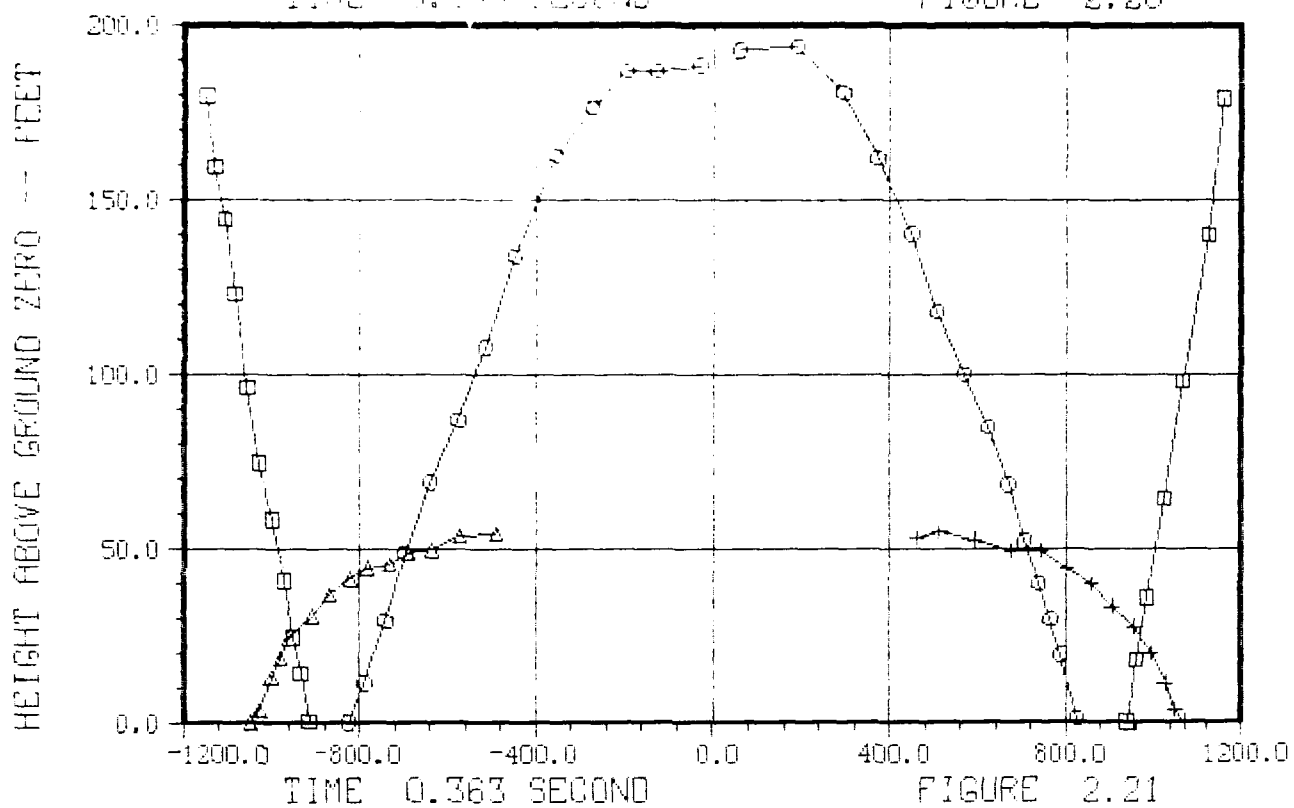
SHOCK PROPAGATION
BREAKAWAY, REFLECTED AND PRECURSOR SHOCKS
TIME 0.333 SECOND

FIGURE 2.18



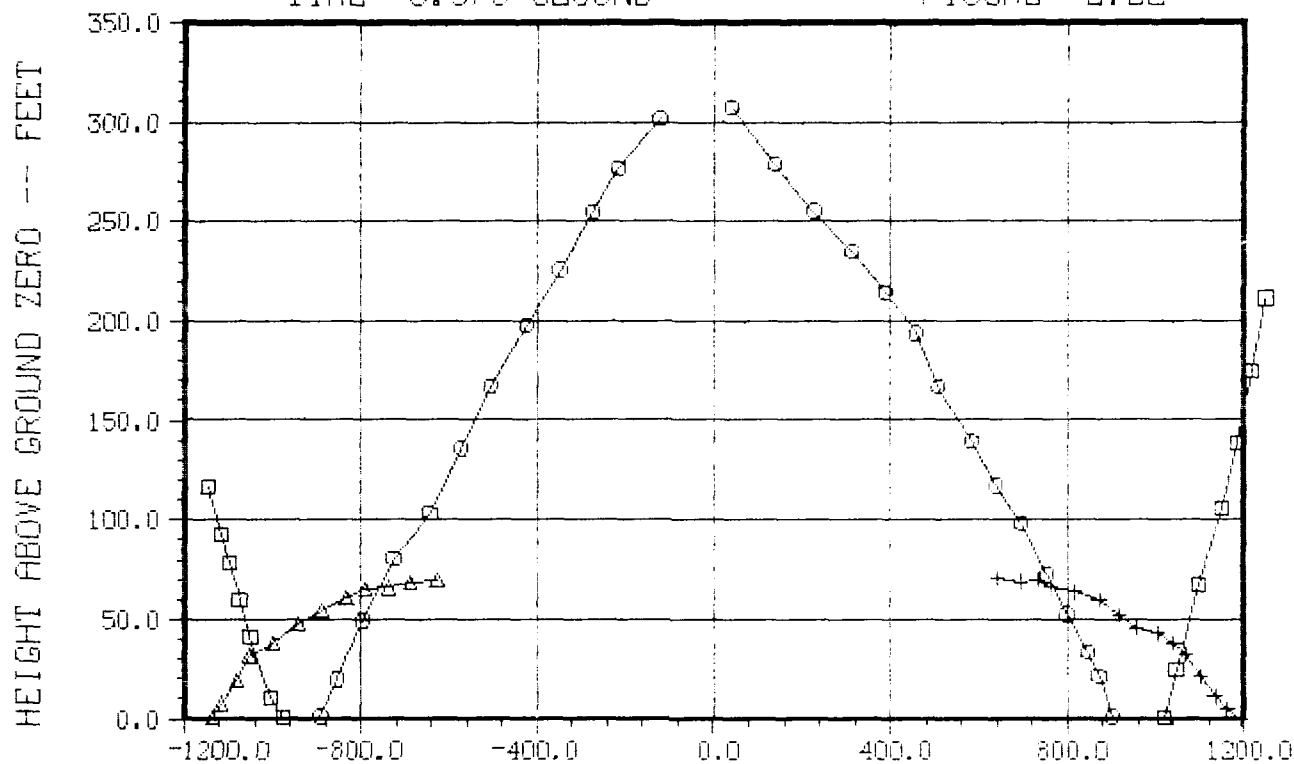
SHOCK PROPAGATION
 BREAKAWAY, REFLECTED AND PRECURSOR SHOCKS
 TIME 0.353 SECONDS

FIGURE 2.20



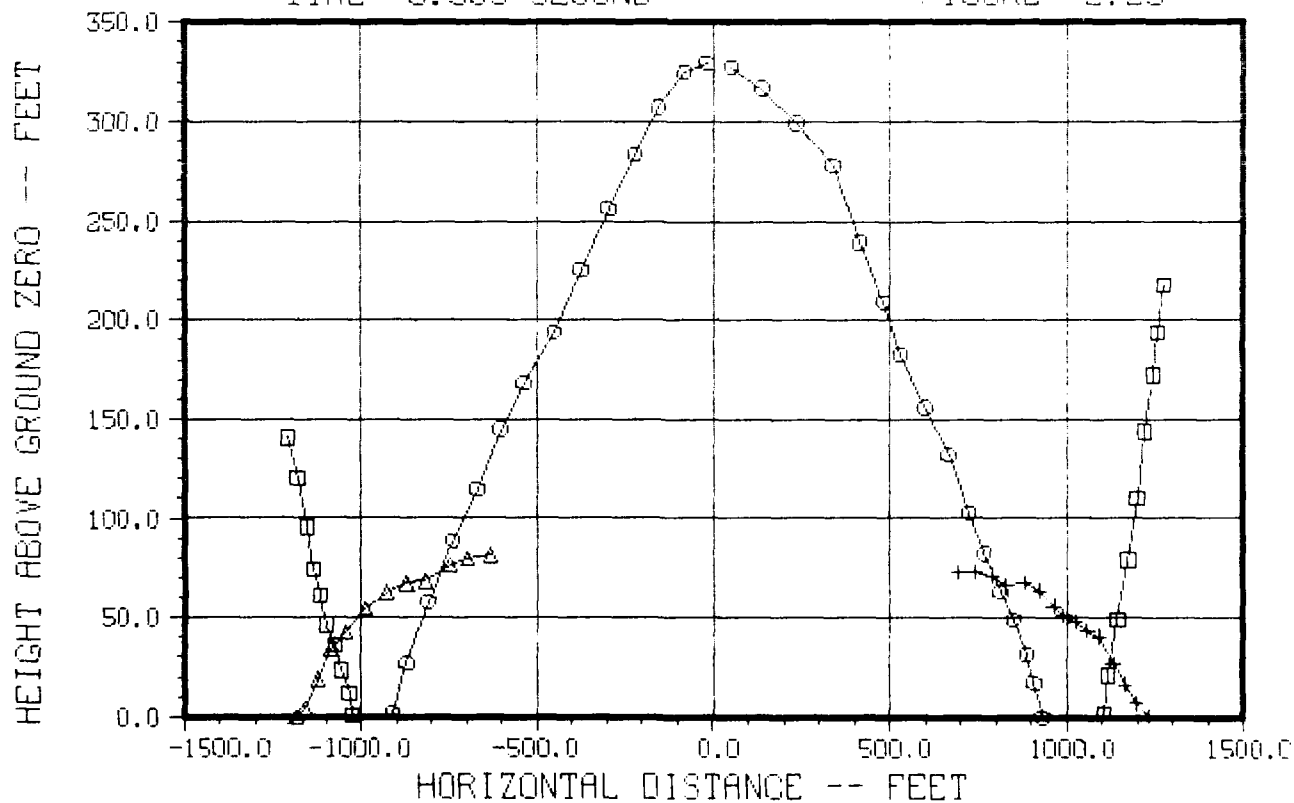
SHOCK PROPAGATION
BREAKAWAY, REFLECTED AND PRECURSOR SHOCKS
TIME 0.373 SECOND

FIGURE 2.22



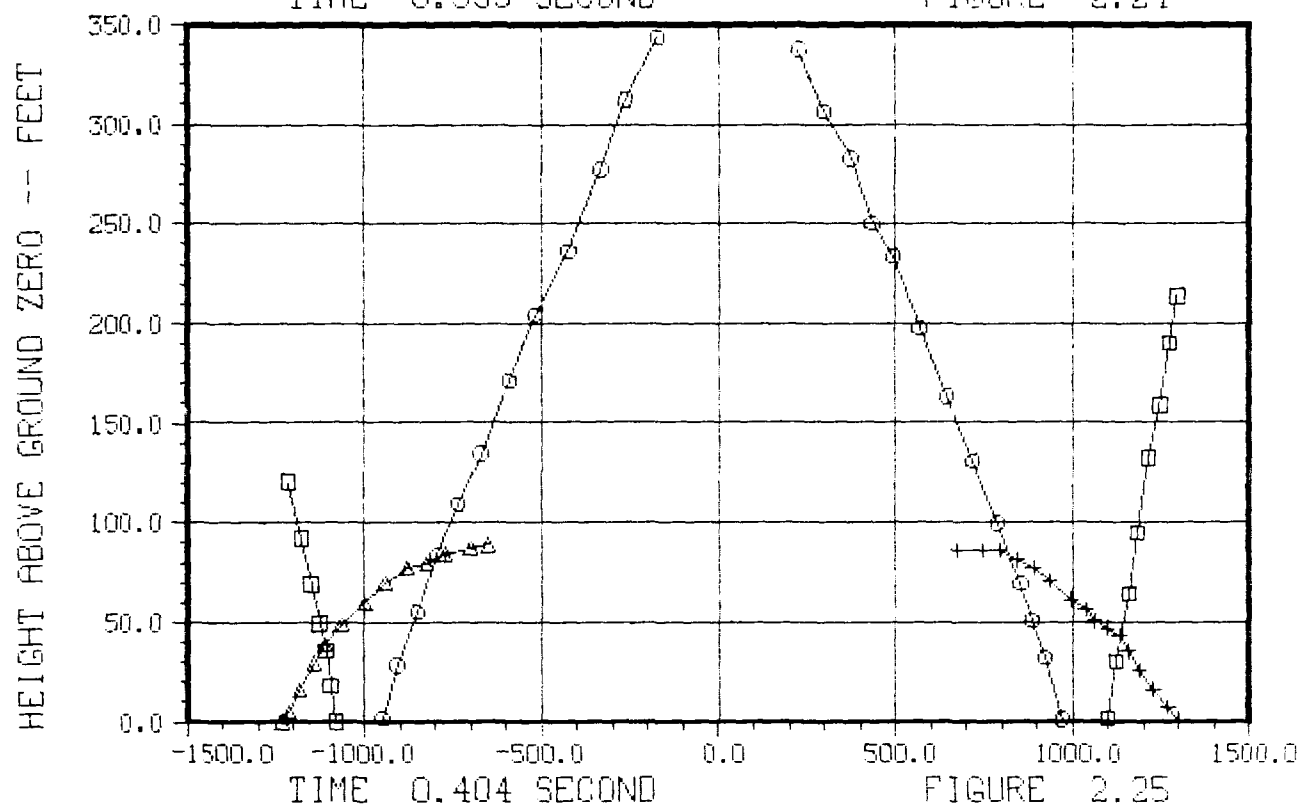
TIME 0.383 SECOND

FIGURE 2.23



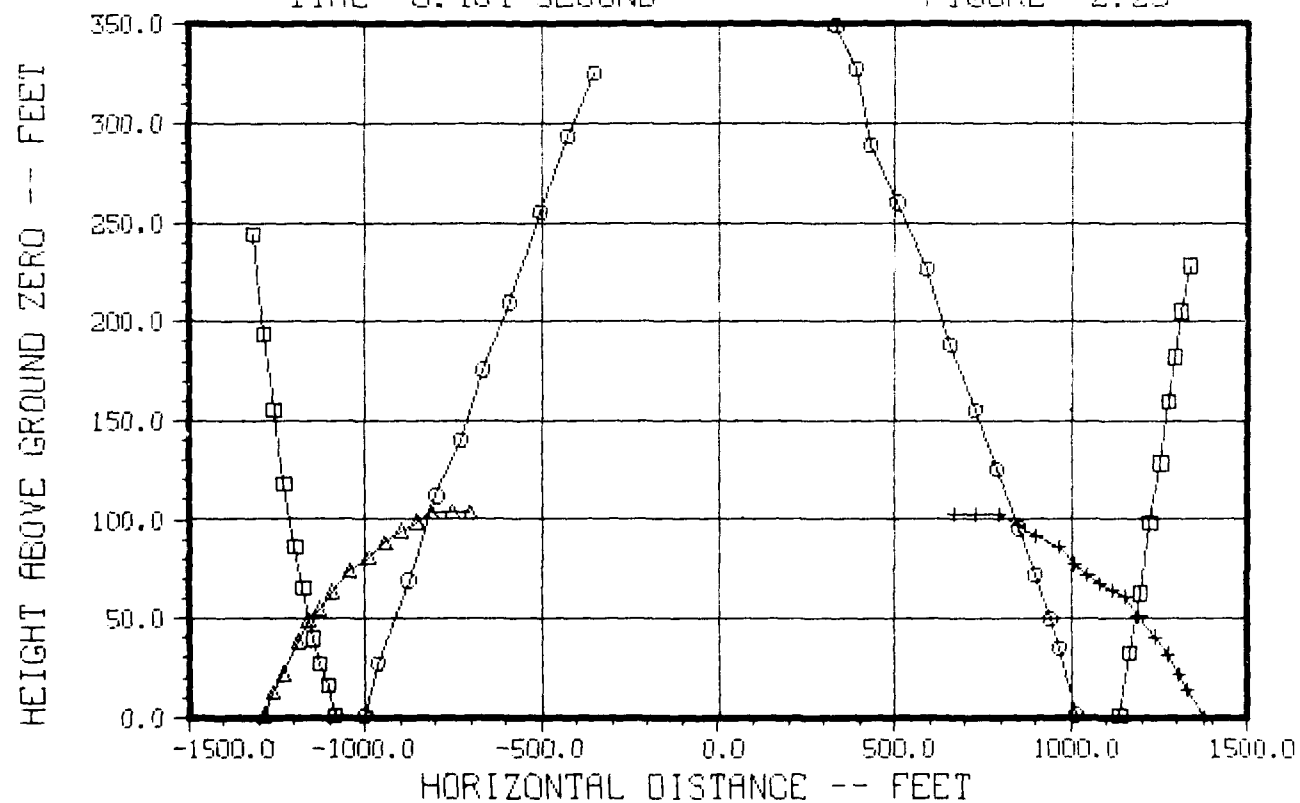
SHOCK PROPAGATION
 BREAKAWAY, REFLECTED AND PRECURSOR SHOCKS
 TIME 0.393 SECOND

FIGURE 2.24



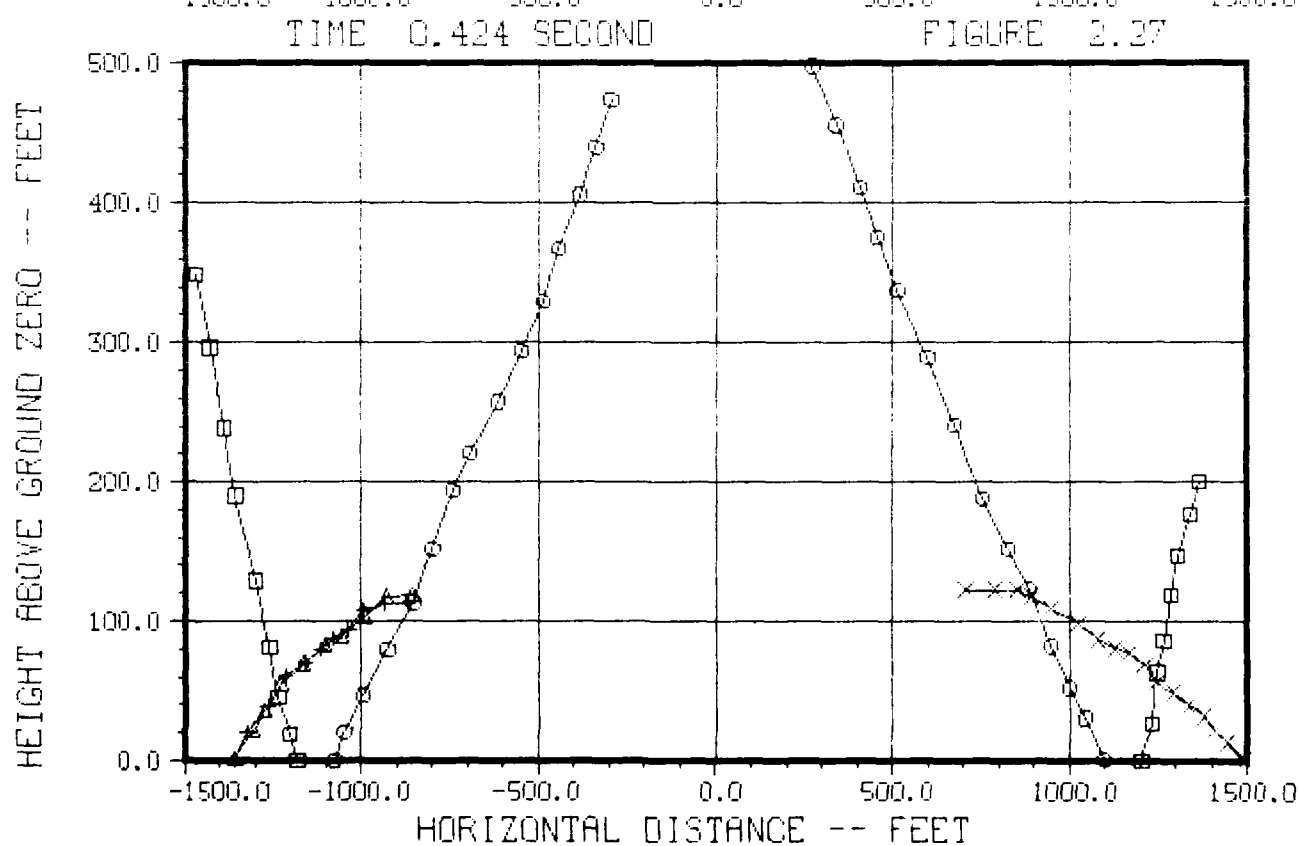
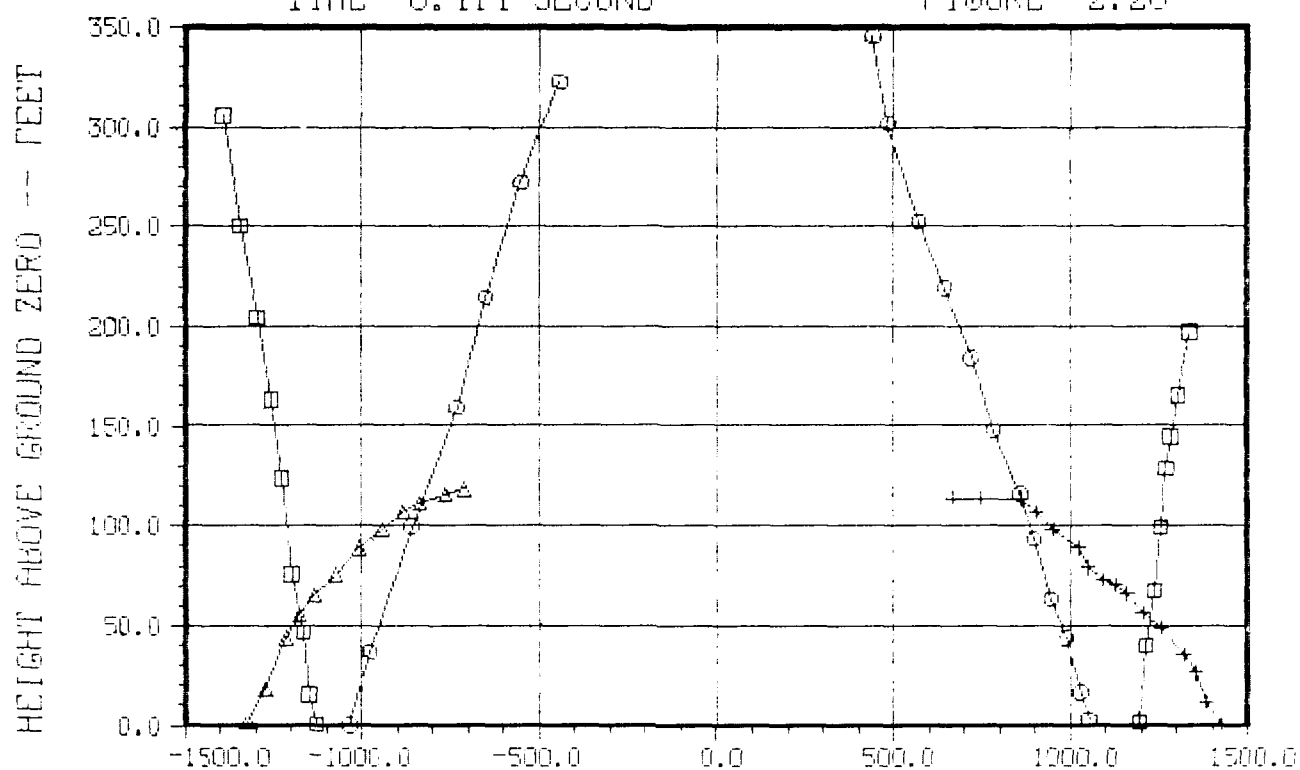
TIME 0.404 SECOND

FIGURE 2.25



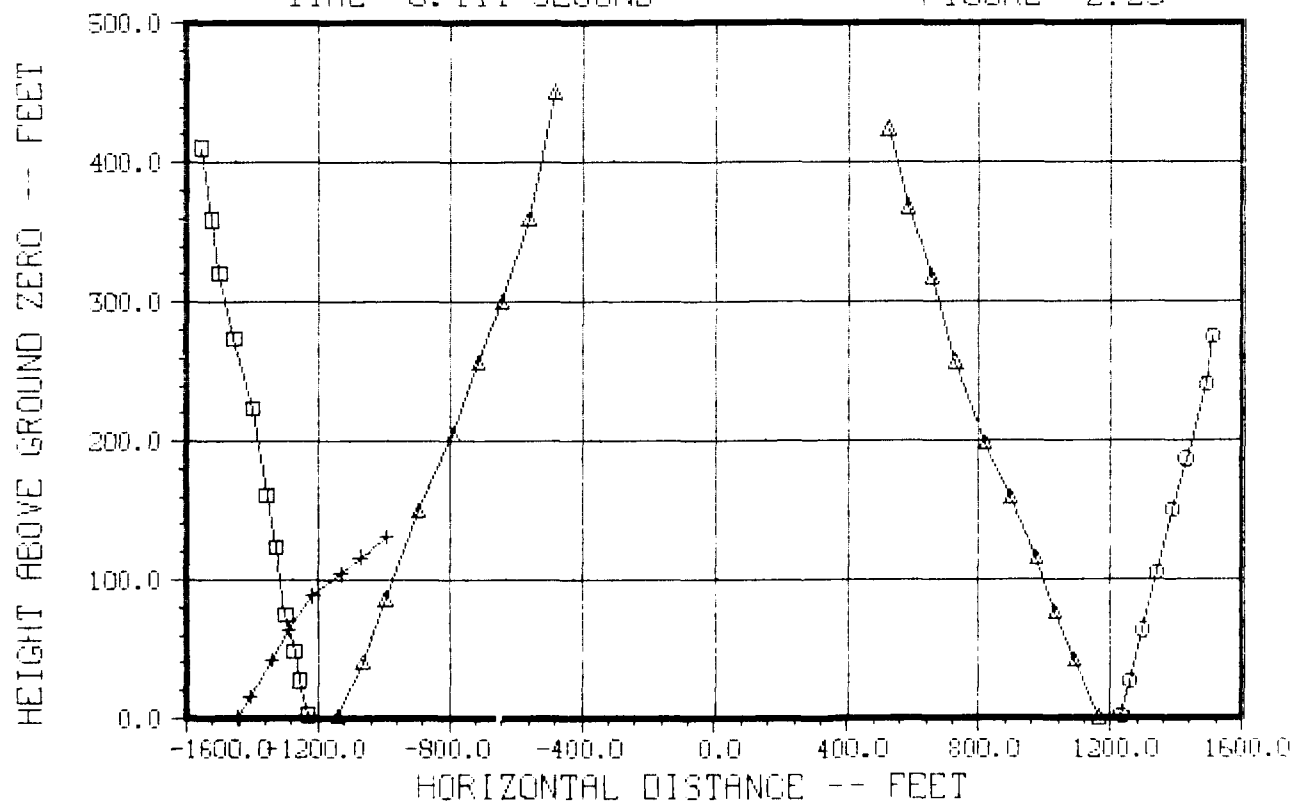
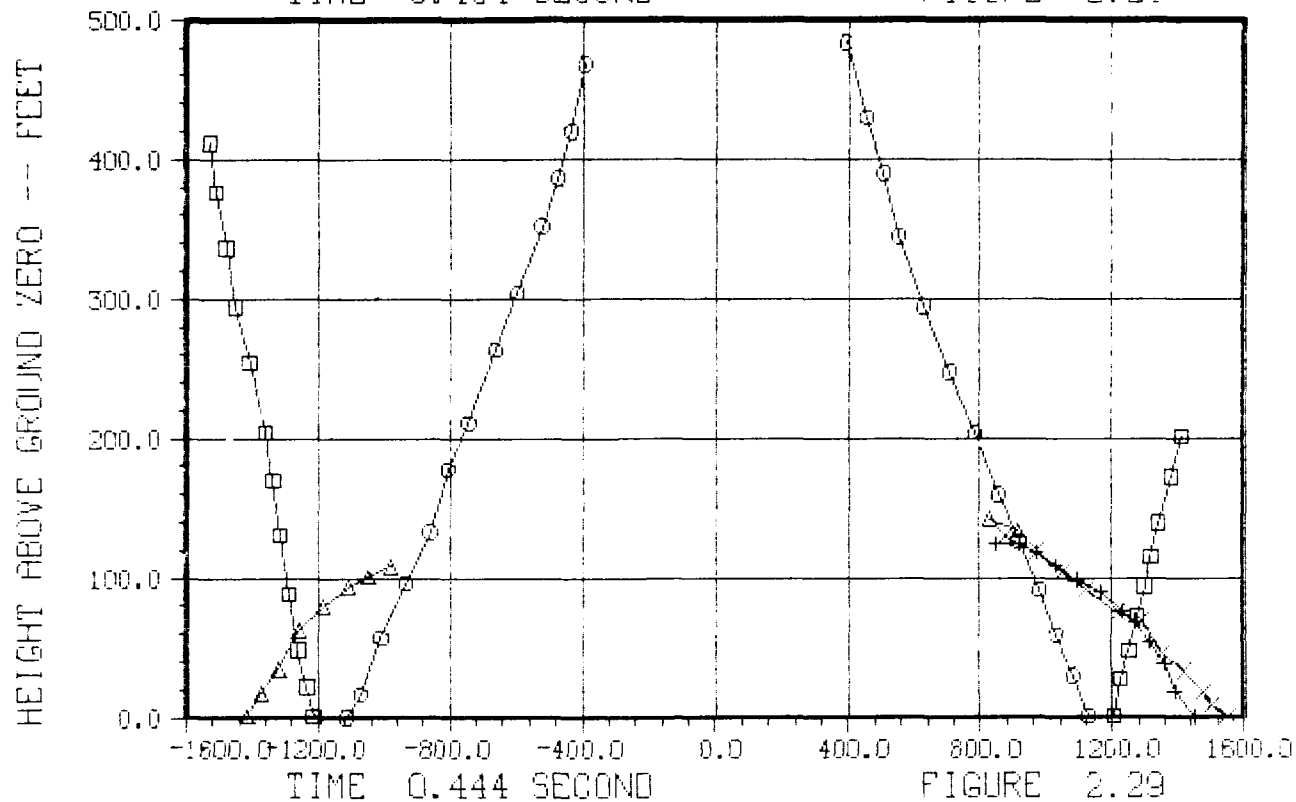
SHOCK PROPAGATION
 BREAKAWAY, REFLECTED AND PRECURSOR SHOCKS
 TIME 0.414 SECOND

FIGURE 2.26

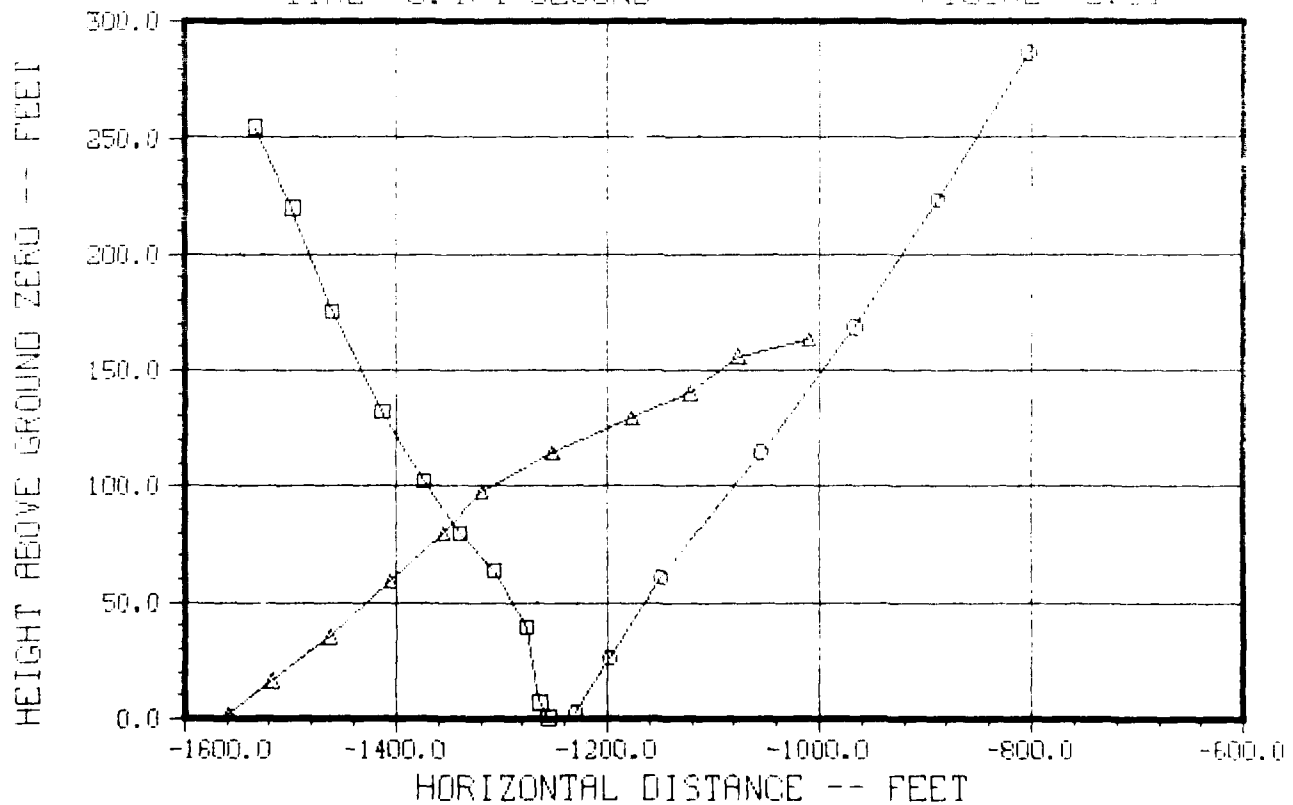
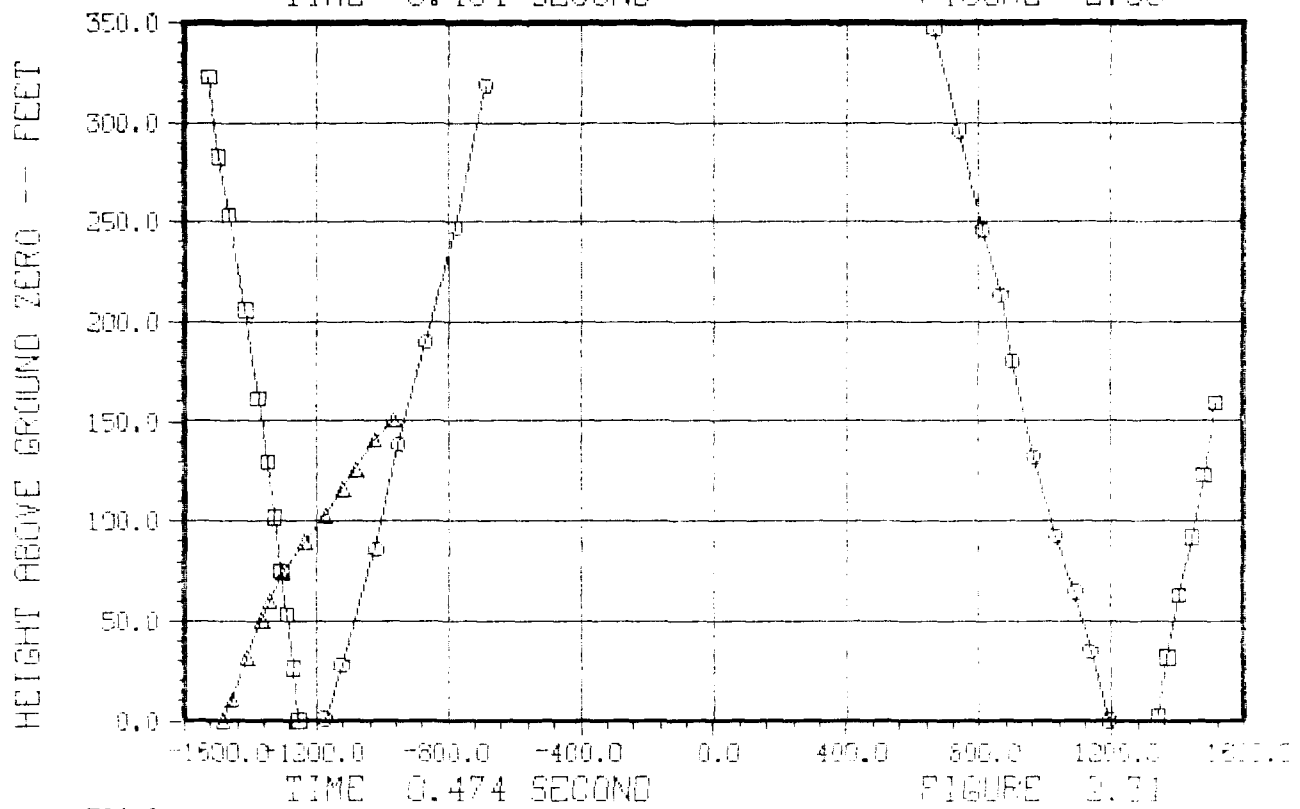


SHOCK PROPAGATION
 BREAKAWAY, REFLECTED AND PRECURSOR SHOCKS
 TIME 0.434 SECOND

FIGURE 2.28

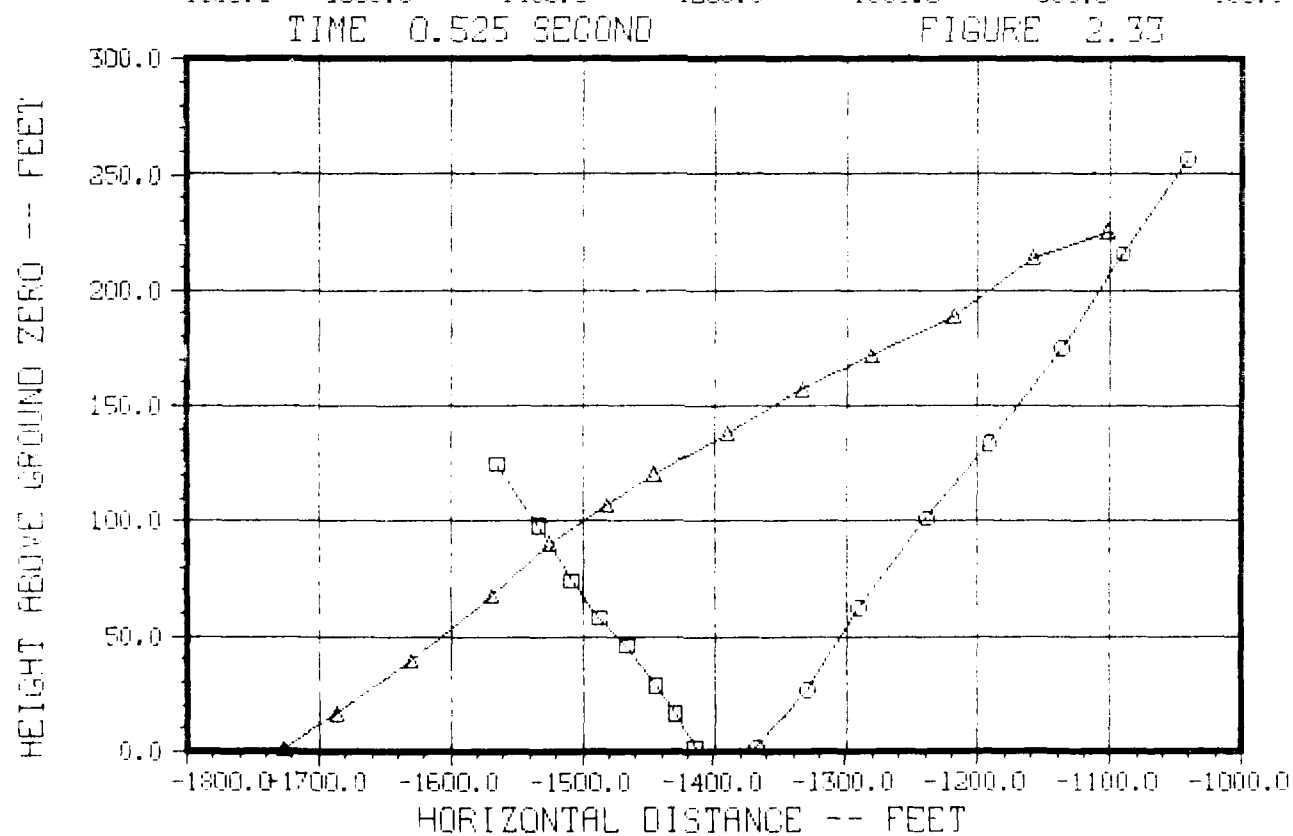
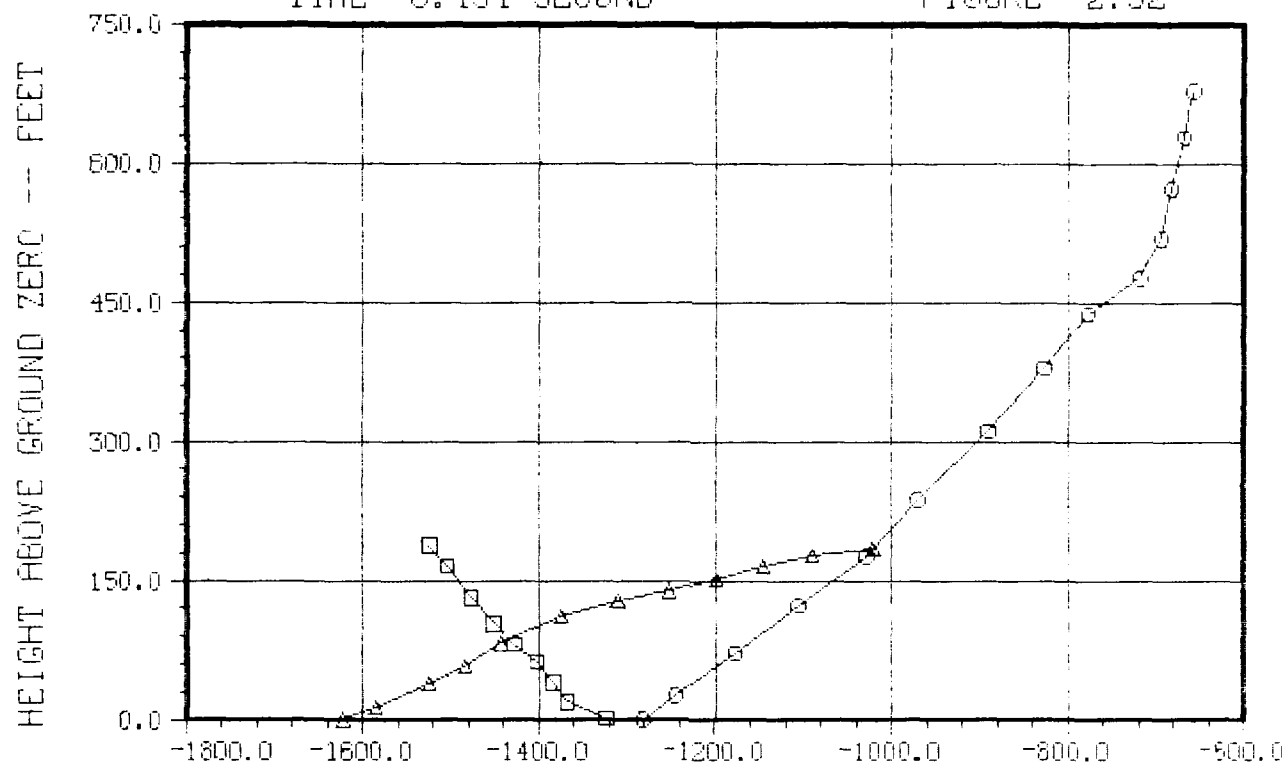


SHOCK PROPAGATION
BREAKAWAY, REFLECTED AND PRECURSOR SHOCKS
TIME 0.454 SECOND FIGURE 2.30



SHOCK PROPAGATION
 BREAKAWAY, REFLECTED AND PRECURSOR SHOCKS
 TIME 0.494 SECOND

FIGURE 2.32



SECTION III

This section presents measurements of thermally-induced dust puffs, or wisps, at Frenchman's Flat during UPSHOT KNOTHOLE Event ENCORE (May 1953; 26.0 KT; HOB 2423 feet). One of the purposes of this event was to develop soil stabilization agents that would be effective in reducing the clouds of smoke and dust that rise from soil surfaces in the vicinity of ground zero. Likewise, various programs of the Air Force, Army and Navy, involving the study of blast effects on structures, were included. To record the desired information of various projects, a total of 193 cameras (typically mounted in pairs, on 18.5-foot towers) were used. These cameras were focused on a specific target, which served as backdrops for the thermal-layer dust measurements.

The measurements are typical of the available data in films that were not considered in this study. As shown by the data, no films were analyzed which recorded dust information at distances that exceeded 4600 feet from ground zero.

Plates 3.1 through 3.4 clearly depict the presence of a dusty layer prior to shock arrival. Each of these plates consists of three scenes. The top scene (A and D) is a snapshot of the structure under study at the time of event minimum (approximately 30 milliseconds). The middle image (B or E) illustrates thermal-induced wisps at approximately one-half the time of shock arrival at the structure. The third scene (C or F) illustrates the conditions just prior to shock arrival time. In all cases, the shock (if seen) would move from left-to-right of the picture.

Plate 3.1 presents scenes at 840 feet from ground zero. These scenes show a 5x5-foot surface of the stabilization experiment. Scenes A, B, and C illustrate the time-behavior of soil around a lignum stabilization pad, while scenes D, E, and F show soil-behavior about a sodium silicate pad. Measurements of the time-dependent heights of dust puffs from these two stations are presented in Figures 3.00, 3.01, 3.02 and 3.03.

Plate 3.2 presents scenes from a structure experiment. Scenes A, B, and C are from a film taken at a station located 1290 feet from ground zero. The height of the barrel is six feet. Scenes D, E, and F are from a station at 1690 feet from ground zero. The nonuniformity of the dust wisps is quite evident, since the camera encompasses a large field of view. The measurements of thermally-induced dust puffs at these two stations are presented in Figures 3.08, 3.11, and 3.12.

Plate 3.3 illustrates scenes from a military equipment-structures study. Scenes A, B, and C depict Army jeeps and trucks at a station 1640 feet from ground zero. Because of the camera-pointing angle, the topological nonuniformity of the cloud puffs is quite evident. Scenes D, E, and F are of a light, tank vehicle located at a station of 2440 feet from ground zero. The black smoke is indicative of burning paint. The cloud puffs and their height variations are clearly illustrated against the tank background. Measurements of layer height versus time from these two stations are summarized in Figures 3.09, 3.10, and 3.17.

Plate 3.4 presents scenes of additional structures- test studies. Scenes A, B, and C are that of a six-foot storage tank located at a station 2330 feet from ground zero. It will be noted that at this location, the jeep in the foreground is quite clear of heavy dust puffs. This difference is due to the fact that it is positioned on stabilized soil. Measurements from these stations are presented in Figures 3.13, 3.14, and 3.28.

Similar scenes could be reproduced from other stations which would yield similar information, as presented in Figures 3.00 through 3.32. These would likewise illustrate nonuniformity in the rising and horizontally-moving puffs. It would appear from these results that the air near the ground surface is nonuniformly heated - at least at the stations where measurements were made. In fact, if cloud wisps are a measure, the heated layer seems to consist of a random distribution of rapidly rising parcels of heated air. The existence of discrete parcels of heated air would seem to imply the development of hot areas on the surface of the ground, which could be related to heterogeneity in the surface albedo.

A word of caution concerning the dust measurements on ENCORE. Occasionally a spike of dust is reported in the measured data at very early times, as shown at 0.3 seconds in Figure 3.05. This spike may not be related to ground surface blow-off. What appears as a "grainy haze", sometimes filling the entire field of view, may, in fact, be emanations from the surface of the 18.5-foot tower which supports the camera⁵. These emanations move by, close to the lens, and consequently, are out of focus. As they pass by the lens, the peak disappears. Should this conclusion be true, then the reported peak at this time is misleading.



A.



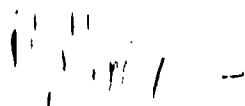
B.



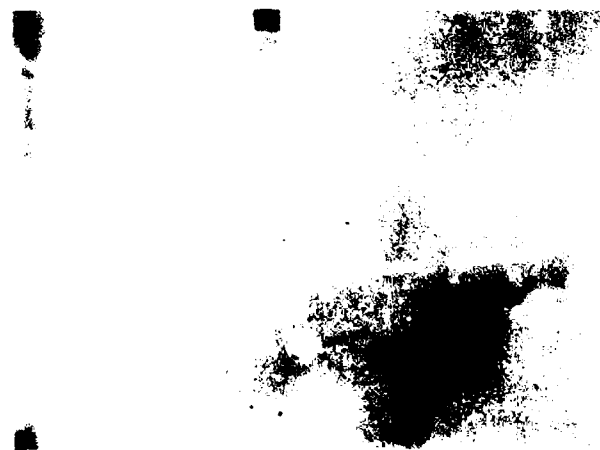
C.



D.



E.

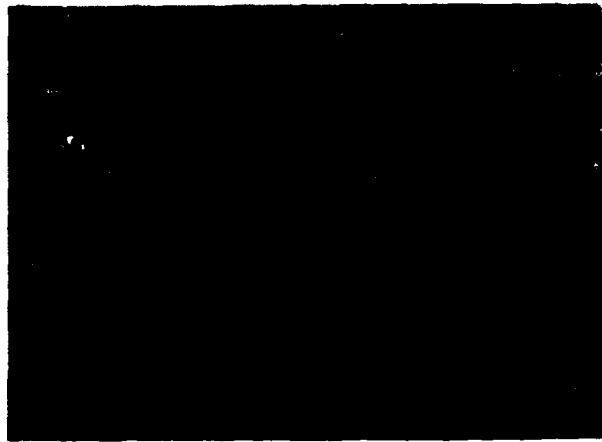


F.

Plate 3.1. Event ENCORE.



D.



D.



D.



D.



D.



D.

Plate 3.2. Event ENCORE.

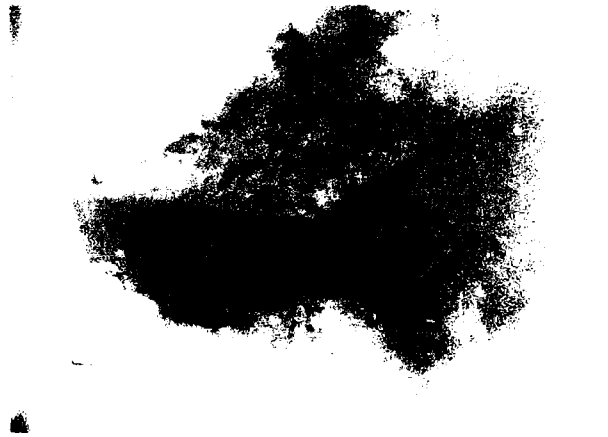
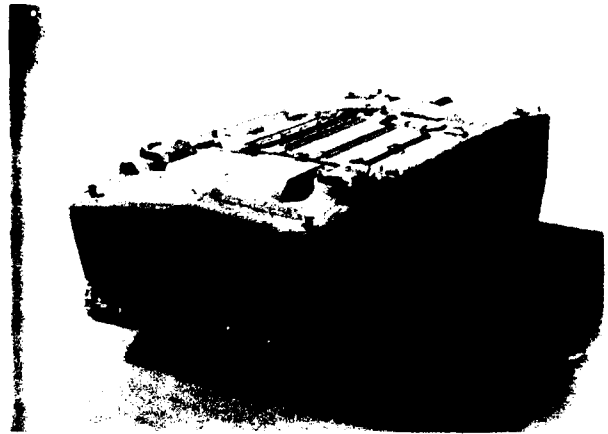
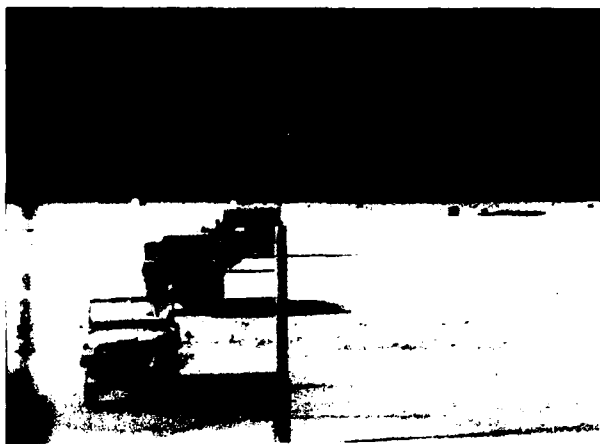


Plate 3.3. Event ENCORE.



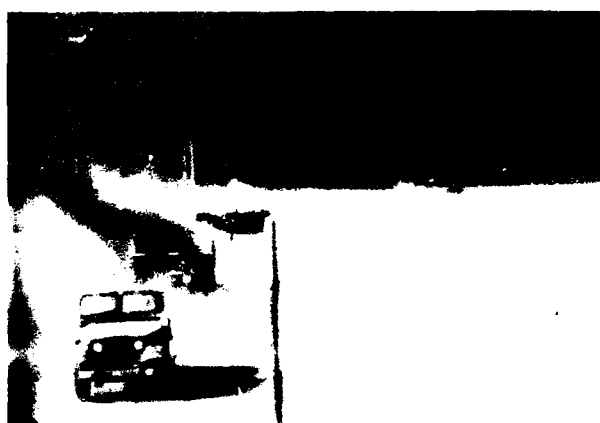
A.



B.



C.



D.



E.



F.

Plate 3.4. Event ENCORE.

DUST RISE - EVENT ENCORE

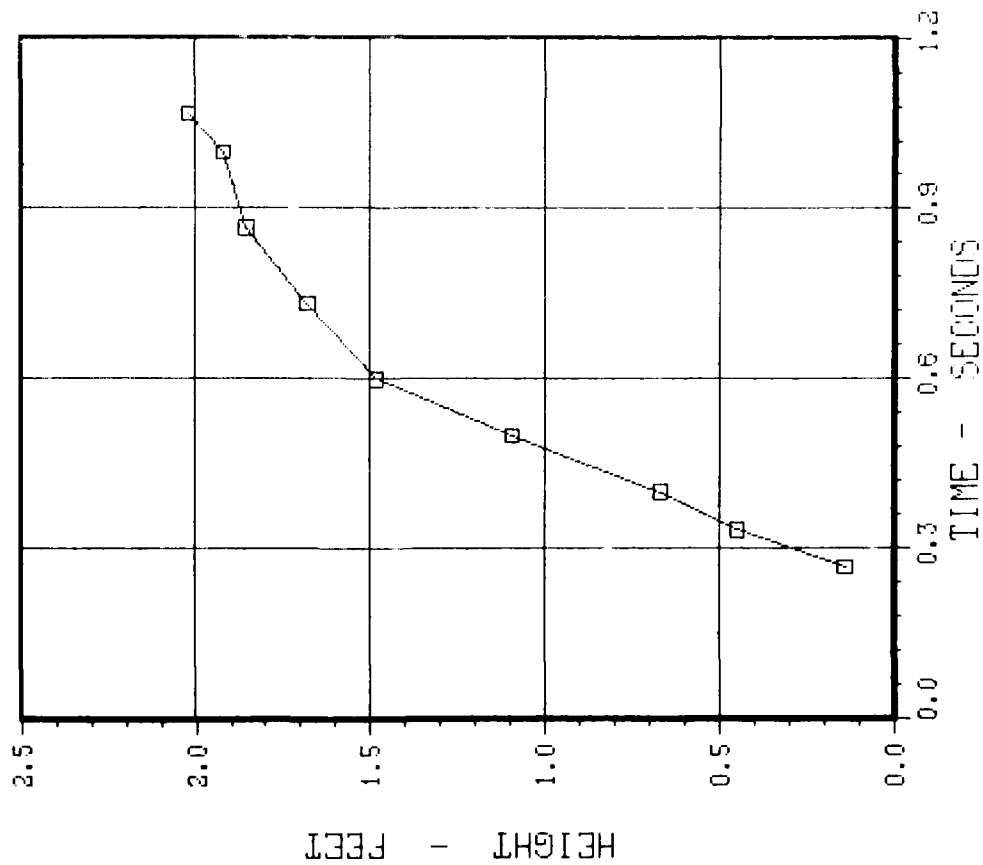
FIGURE 3.00 FILM 16689

DISTANCE FROM GROUND ZERO 840 FEET

SHOCK ARRIVAL TIME 1.10 SECONDS

PEAK PRESSURE 28.0 PSI

THERMAL ENERGY 1300CAL/(CM)**2



DUST RISE - EVENT ENCORE

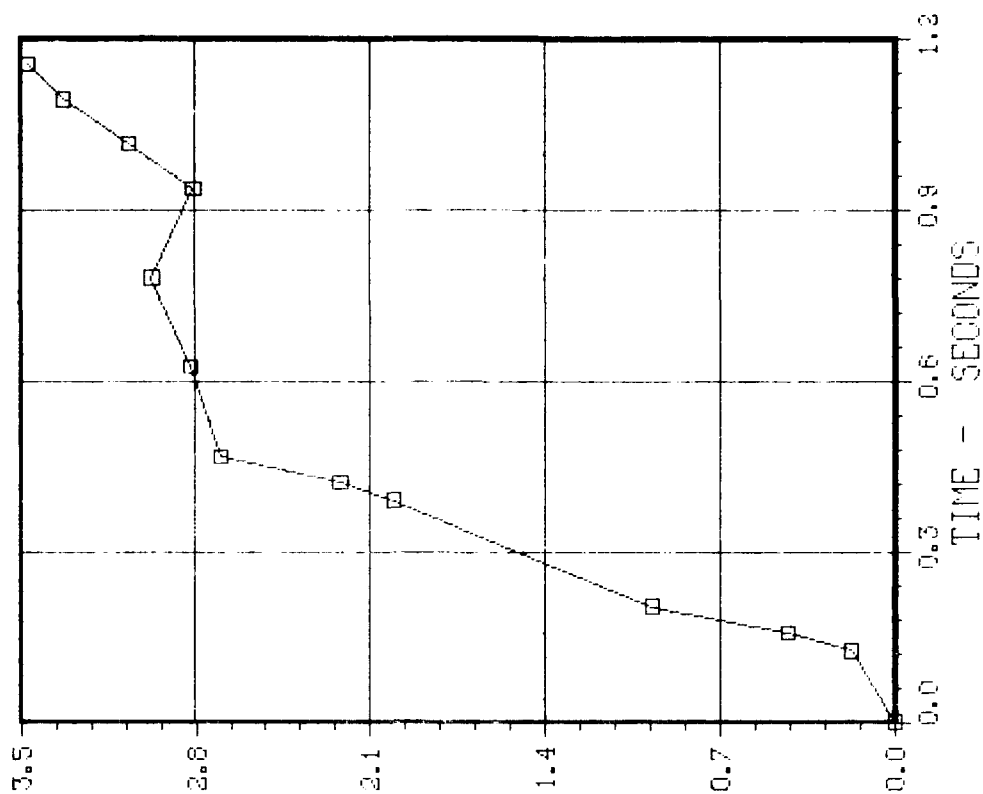
FIGURE 3.01 FILM 16690

DISTANCE FROM GROUND ZERO 840 FEET

SHOCK ARRIVAL TIME 1.17 SECONDS

PEAK PRESSURE 28.0 PSI

THERMAL ENERGY 1300CAL/(CM)**2



DUST RISE - EVENT ENCORE

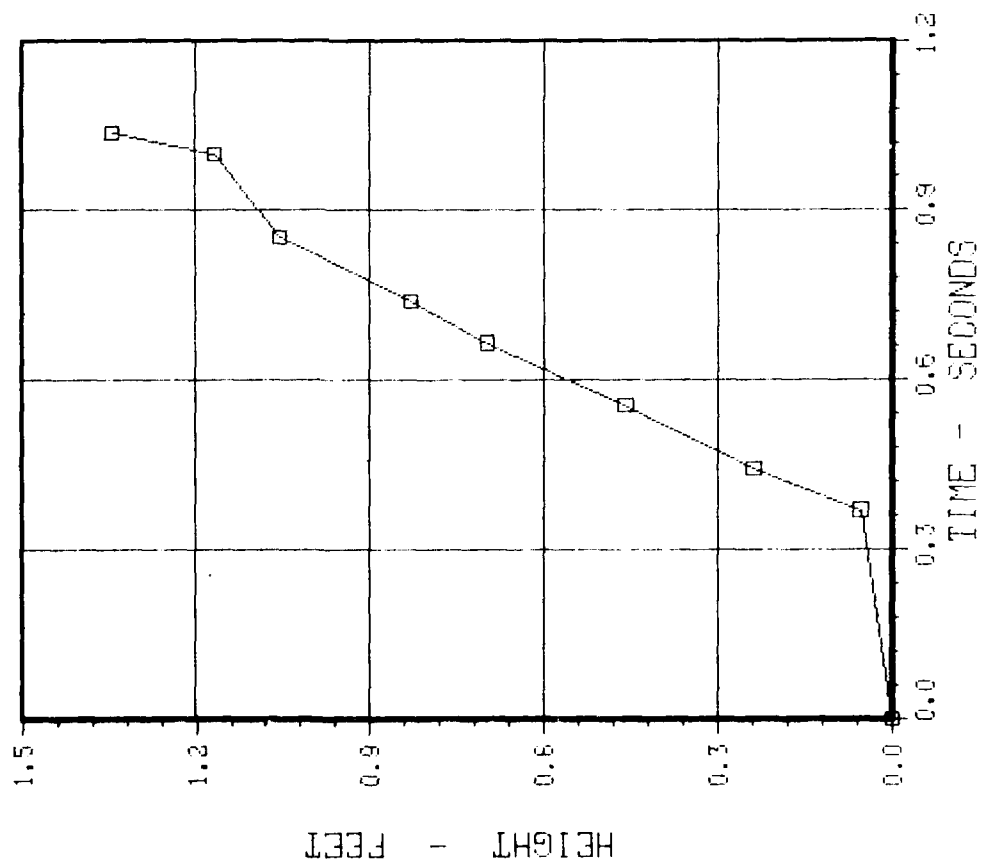
FIGURE 3.02 FILM 16691

DISTANCE FROM GROUND ZERO 840 FEET

SHOCK ARRIVAL TIME 1.07 SECONDS

PEAK PRESSURE 28.0 PSI

THERMAL ENERGY 1300CAL/(CM)**2



DUST RISE - EVENT ENCORE

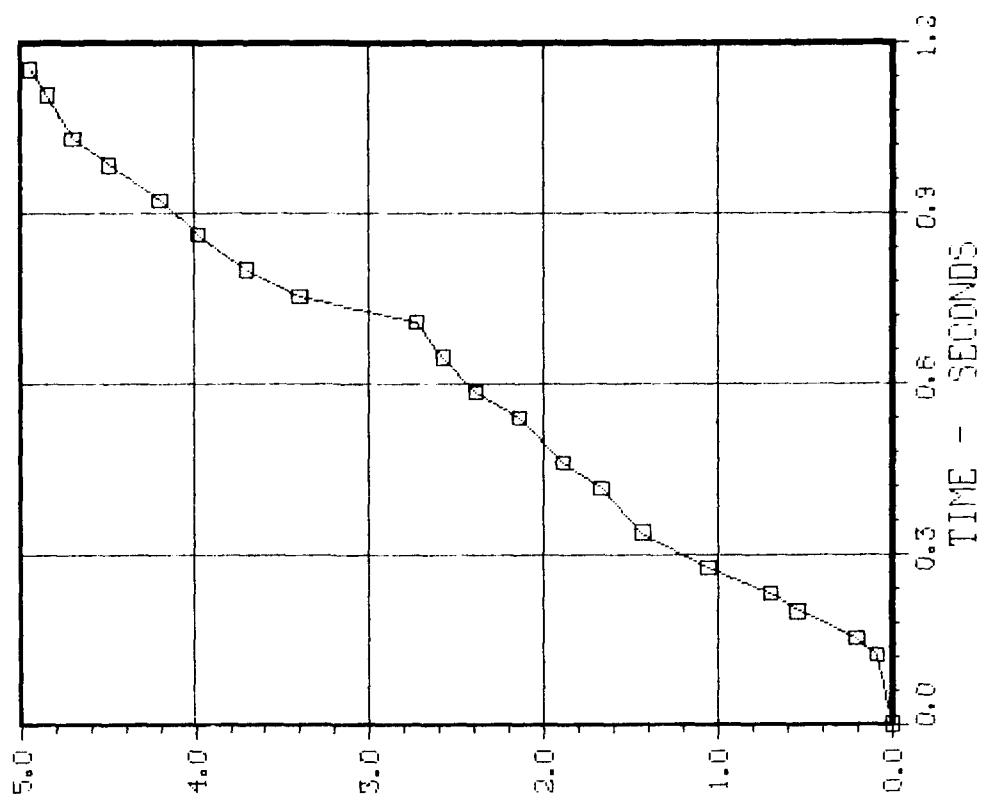
FIGURE 3.03 FILM 16692

DISTANCE FROM GROUND ZERO 840 FEET

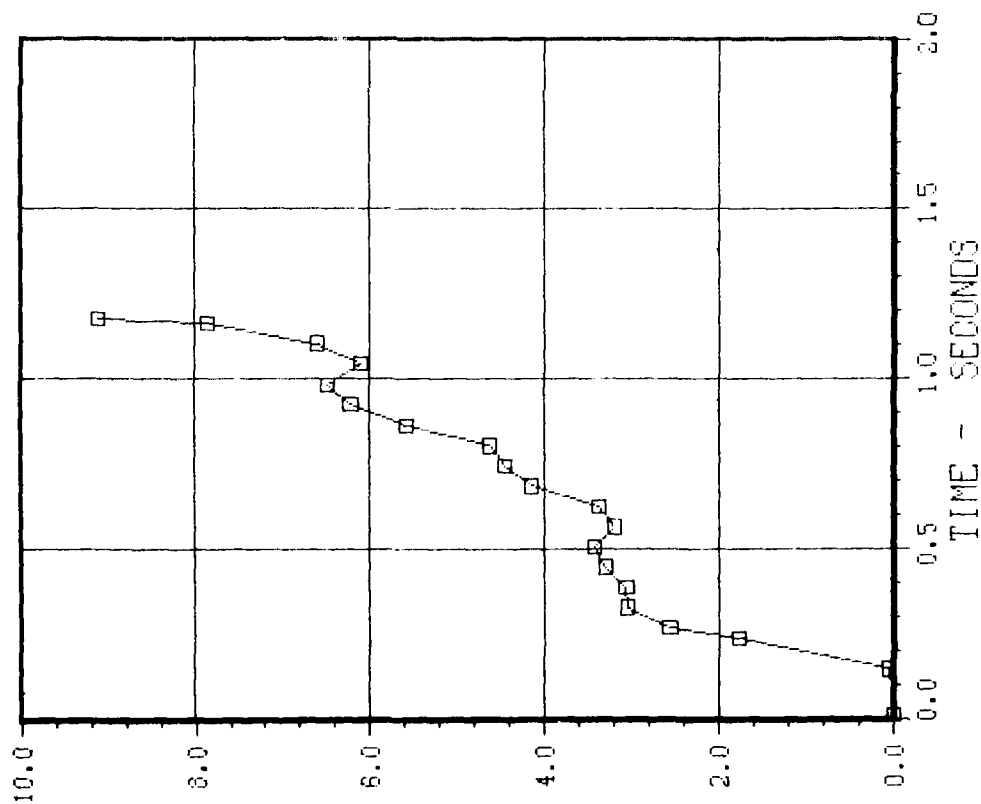
SHOCK ARRIVAL TIME 1.12 SECONDS

PEAK PRESSURE 28.0 PSI

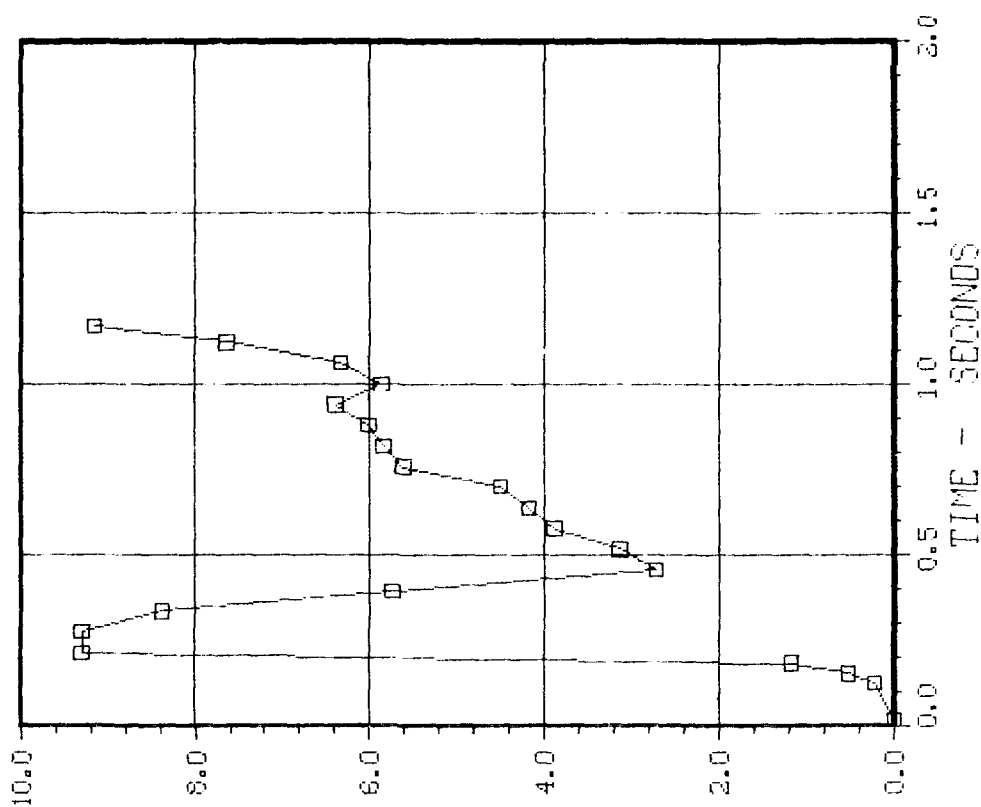
THERMAL ENERGY 1300CAL/(CM)**2



DUST RISE - EVENT ENDURE
 FIGURE 3.04 FILM 16554
 DISTANCE FROM GROUND ZERO 1080 FEET
 SHOCK ARRIVAL TIME 1.21 SECONDS
 PEAK PRESSURE 18.7 PSI
 THERMAL ENERGY 1200AL/(CM)**2

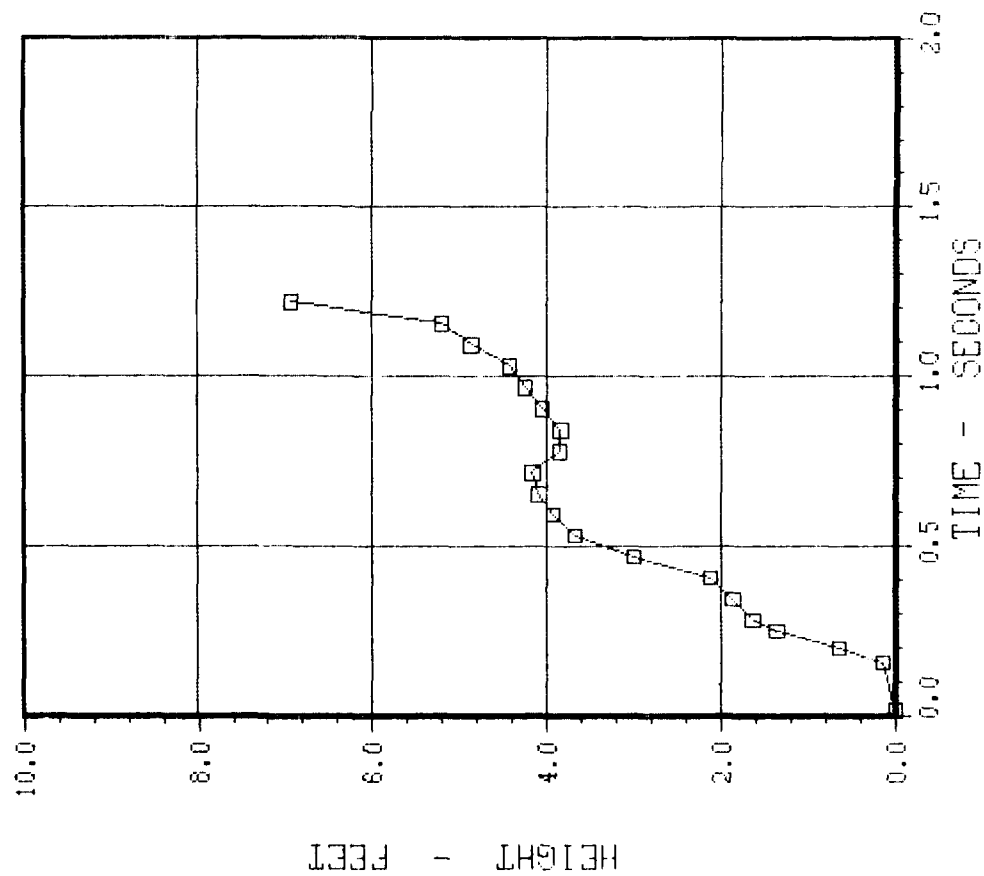


DUST RISE - EVENT ENDURE
 FIGURE 3.05 FILM 16555
 DISTANCE FROM GROUND ZERO 1080 FEET
 SHOCK ARRIVAL TIME 1.18 SECONDS
 PEAK PRESSURE 18.7 PSI
 THERMAL ENERGY 1200AL/(CM)**2

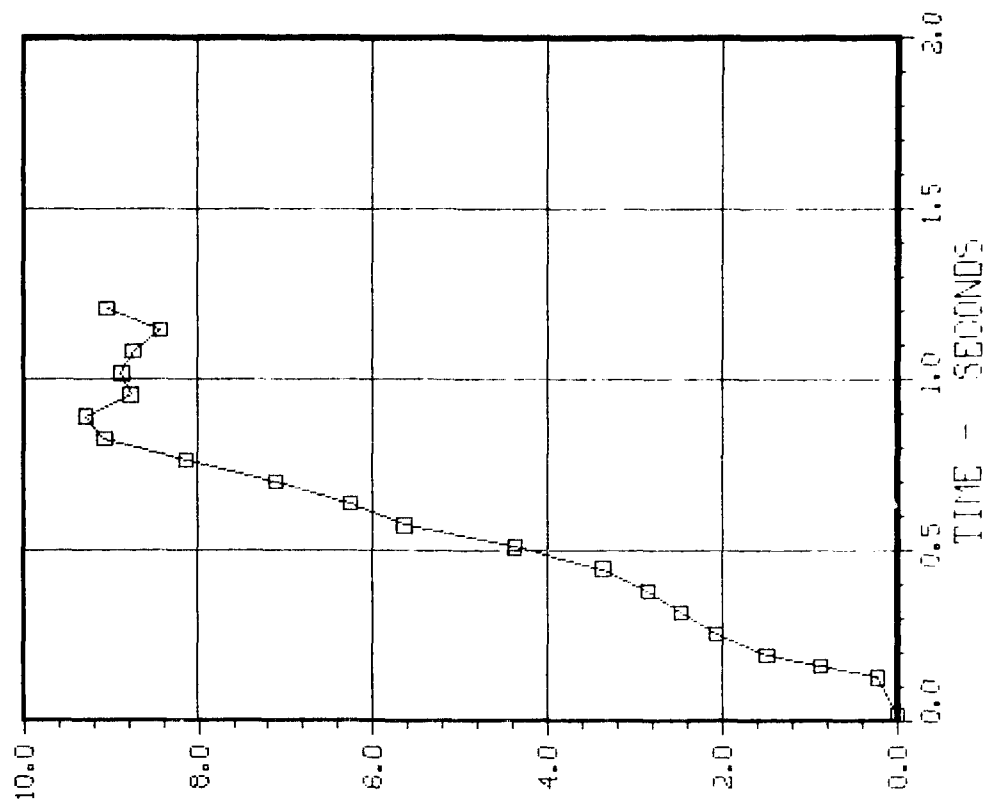


HEIGHT - FEET

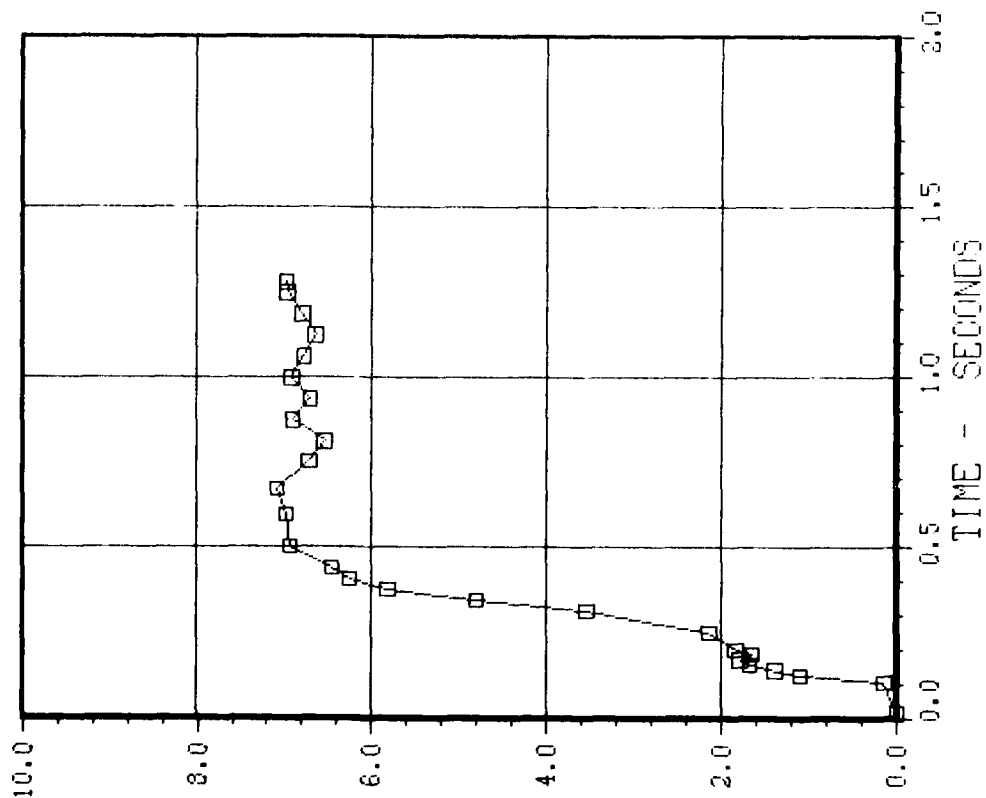
DUST RISE - EVENT ENCORE
 FIGURE 3.06 FILM 16552
 DISTANCE FROM GROUND ZERO 1220 FEET
 SHOCK ARRIVAL TIME 1.23 SECONDS
 PEAK PRESSURE 17.5 PSI
 THERMAL ENERGY 1150CAL/(CM)**2



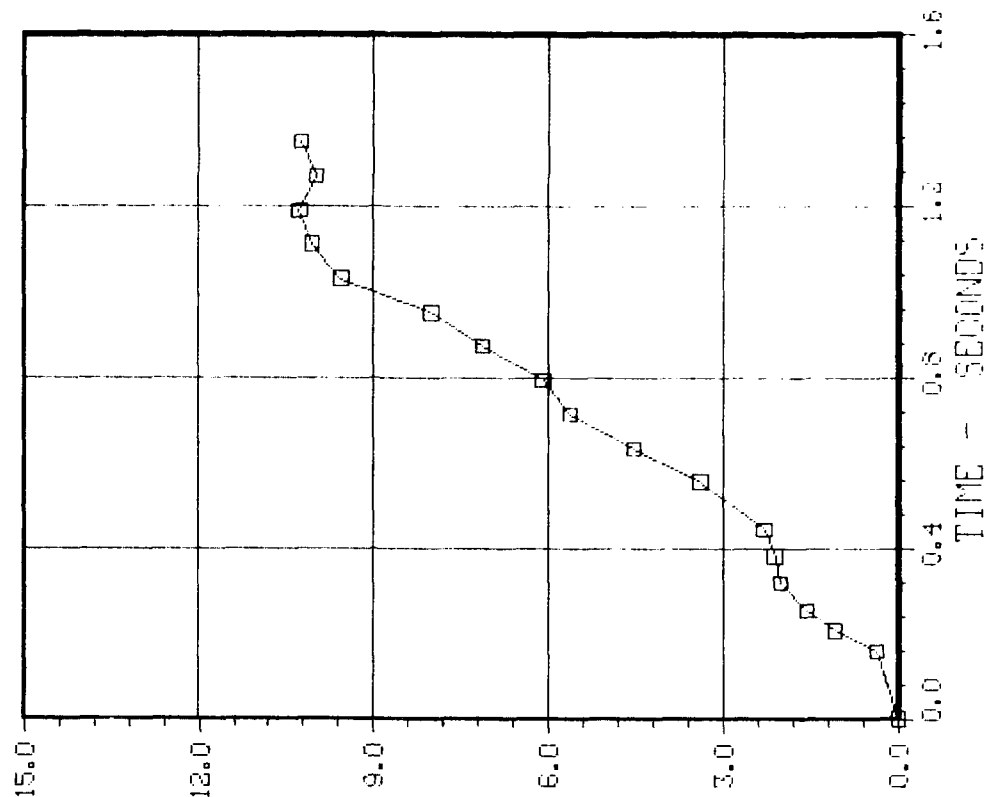
DUST RISE - EVENT ENCORE
 FIGURE 3.07 FILM 16553
 DISTANCE FROM GROUND ZERO 1220 FEET
 SHOCK ARRIVAL TIME 1.24 SECONDS
 PEAK PRESSURE 17.5 PSI
 THERMAL ENERGY 1150CAL/(CM)**2



DUST RISE - EVENT ENCORE
 FIGURE 3.08 FILM 16551
 DISTANCE FROM GROUND ZERO 1290 FEET
 SHOCK ARRIVAL TIME 1.30 SECONDS
 PEAK PRESSURE 16.9 PSI
 THERMAL ENERGY 1140CAL/(CM)**2



DUST RISE - EVENT ENCORE
 FIGURE 3.09 FILM 16538
 DISTANCE FROM GROUND ZERO 1640 FEET
 SHOCK ARRIVAL TIME 1.37 SECONDS
 PEAK PRESSURE 14.5 PSI
 THERMAL ENERGY 97 CAL/(CM)**2



HEIGHT - FEET

DUST RISE - EVENT ENCORE

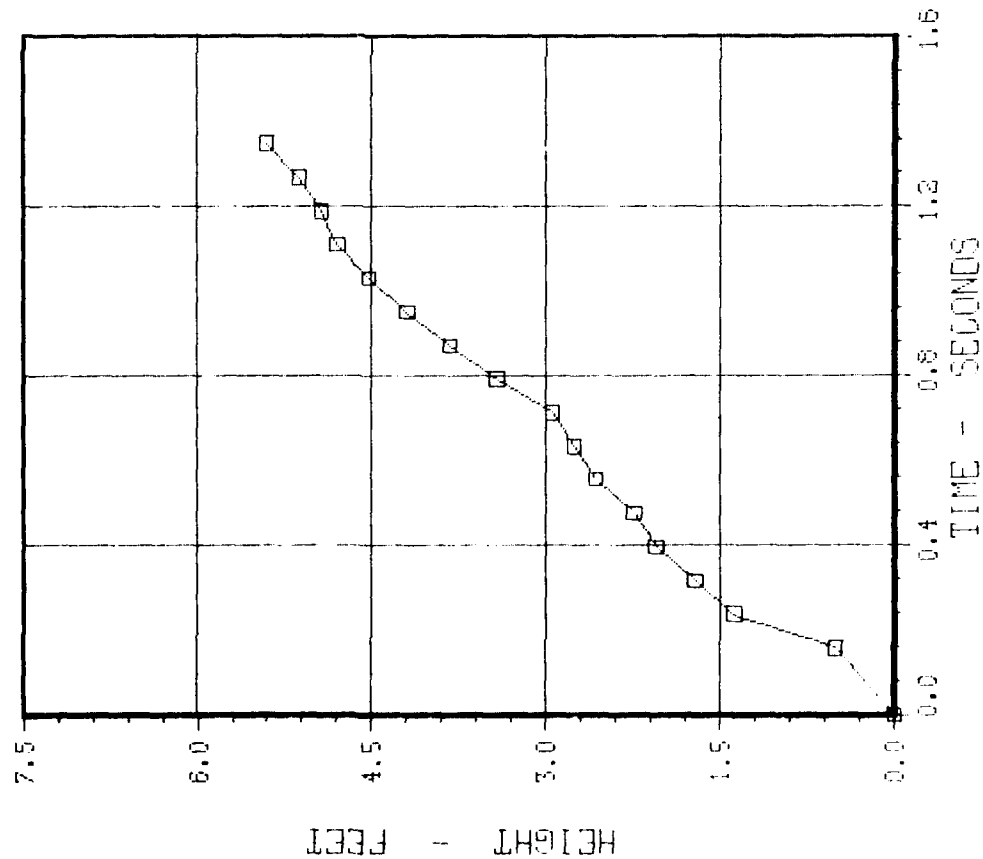
FIGURE 3.10 FILM 16539

DISTANCE FROM GROUND ZERO 1640 FEET

SHOCK ARRIVAL TIME 1.35 SECONDS

PEAK PRESSURE 14.5 PSI

THERMAL ENERGY 97 CAL/(CM)**2



DUST RISE - EVENT ENCORE

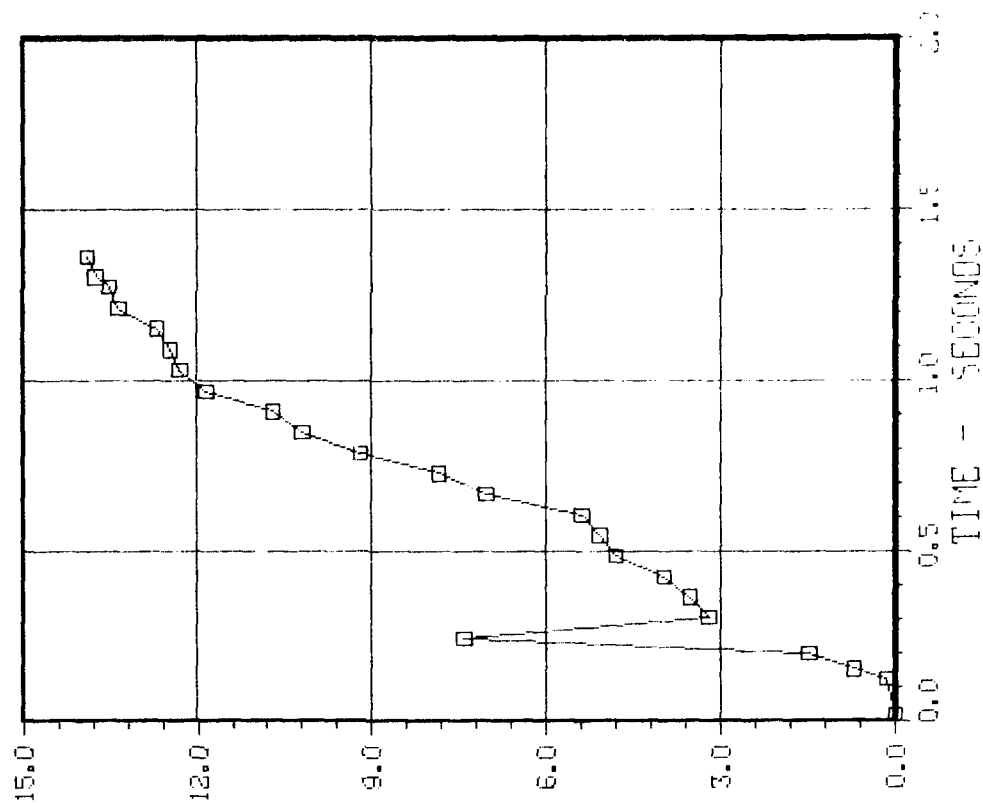
FIGURE 3.11 FILM 16556

DISTANCE FROM GROUND ZERO 1690 FEET

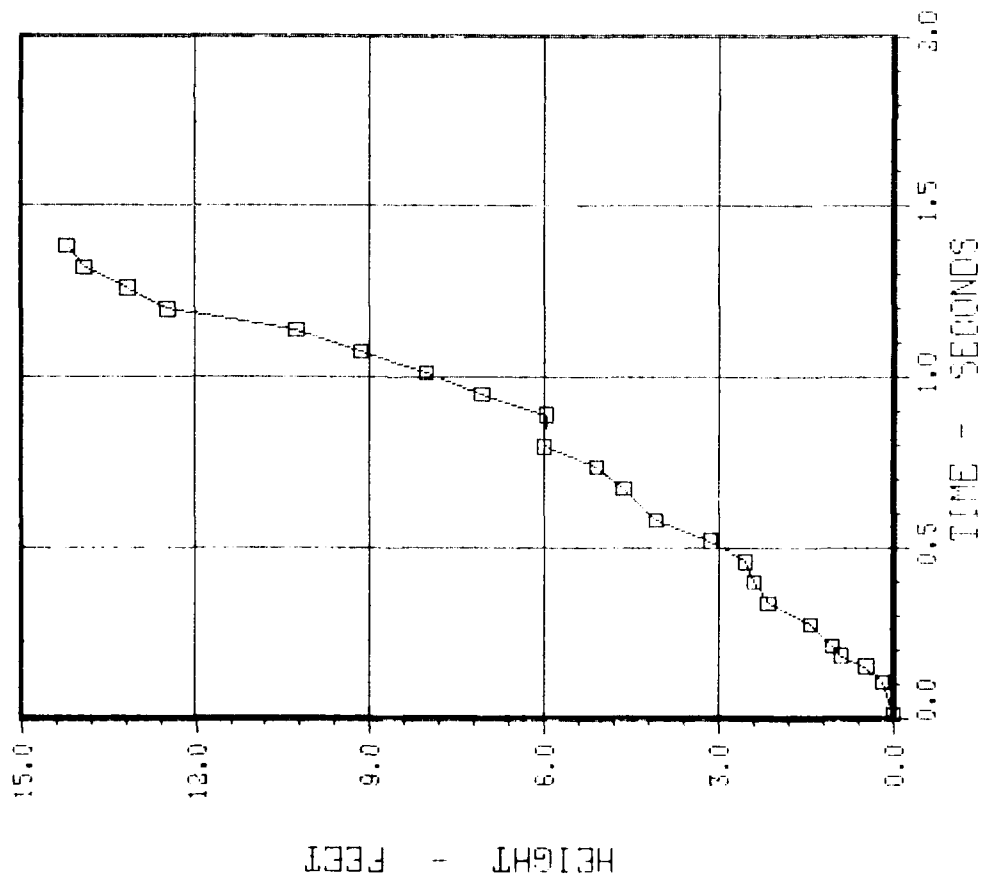
SHOCK ARRIVAL TIME 1.38 SECONDS

PEAK PRESSURE 14.1 PSI

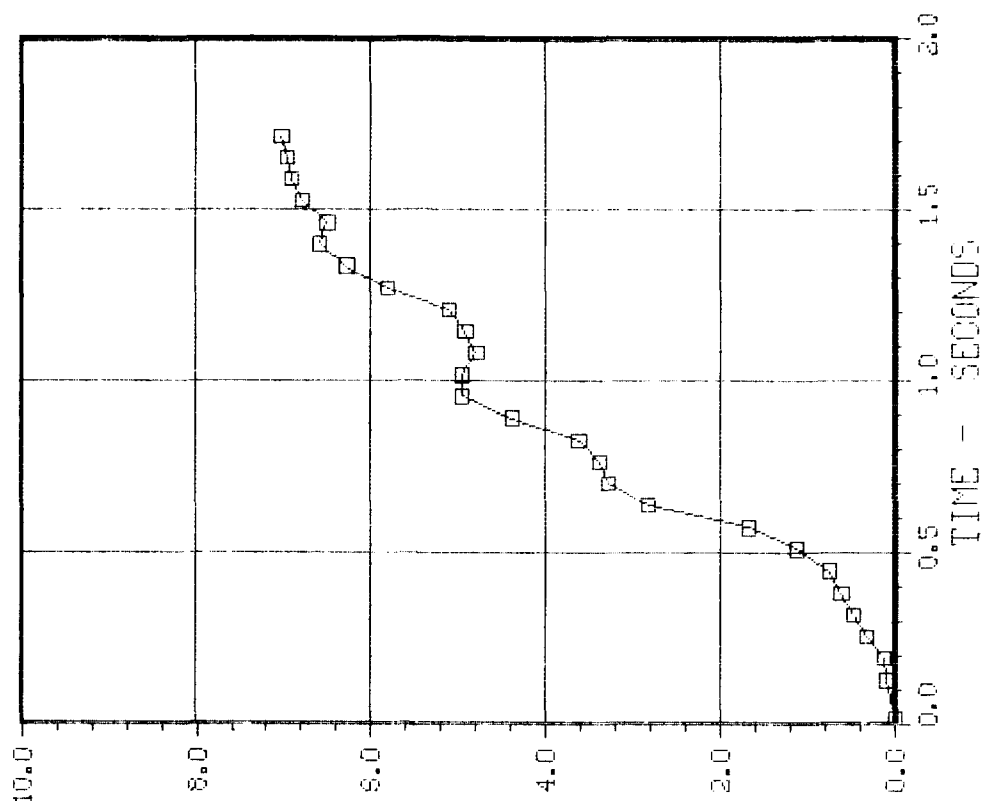
THERMAL ENERGY 97 CAL/(CM)**2



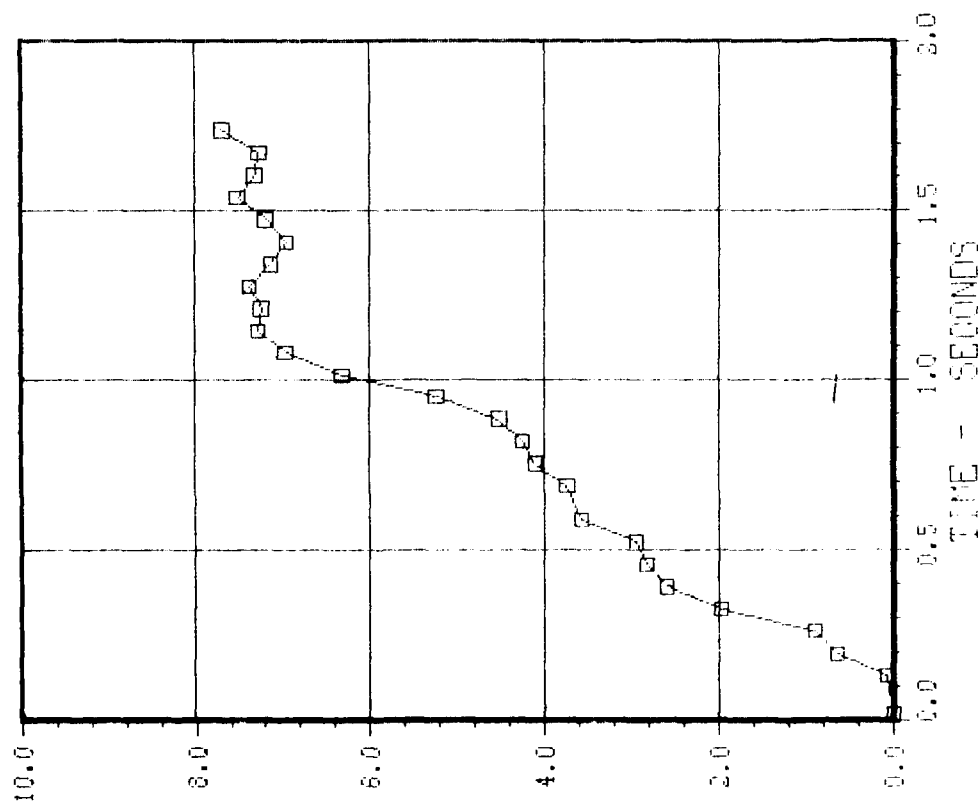
DUST RISE - EVENT ENCORE
 FIGURE 3.12 FILM 16557
 DISTANCE FROM GROUND ZERO 1690 FEET
 SHOCK ARRIVAL TIME 1.40 SECONDS
 PEAK PRESSURE 14.1 PSI
 THERMAL ENERGY 97 CAL/(CM)**2



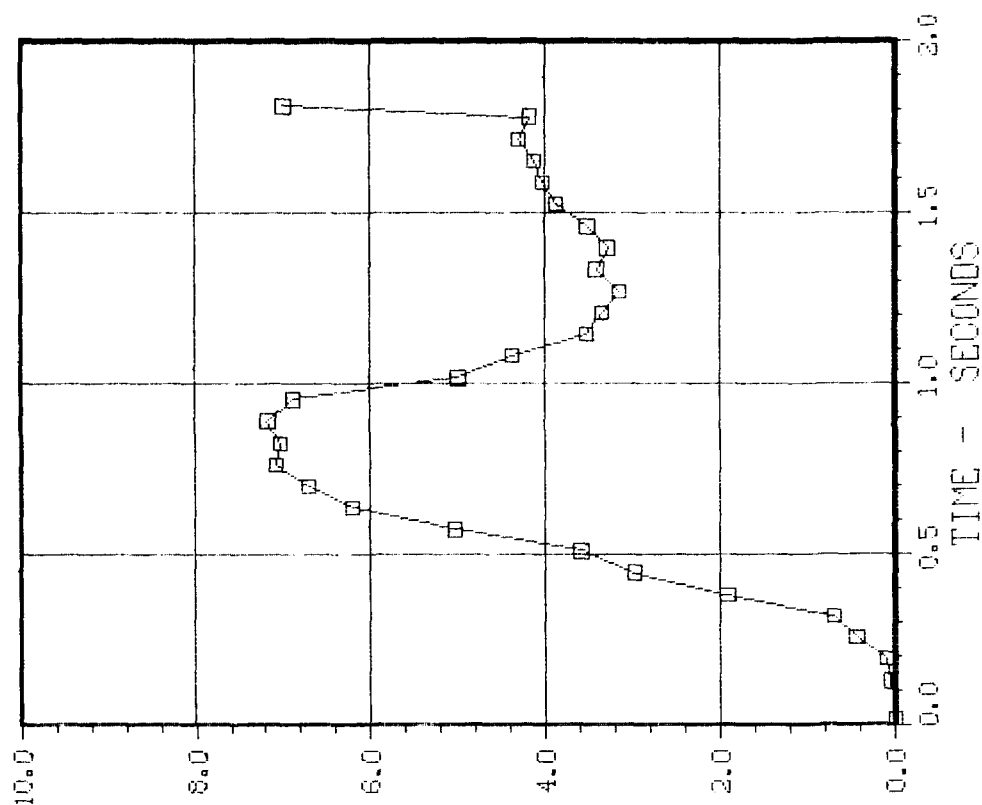
DUST RISE - EVENT ENCORE
 FIGURE 3.13 FILM 16560
 DISTANCE FROM GROUND ZERO 2330 FEET
 SHOCK ARRIVAL TIME 1.71 SECONDS
 PEAK PRESSURE 11.4 PSI
 THERMAL ENERGY 76 CAL/(CM)**2



DUST RISE - EVENT ENCORE
 FIGURE 3.14 FILM 16561
 DISTANCE FROM GROUND ZERO 2330 FEET
 SHOCK ARRIVAL TIME 1.77 SECONDS
 PEAK PRESSURE 11.4 PSI
 THERMAL ENERGY 76 CAL/(CM)**2

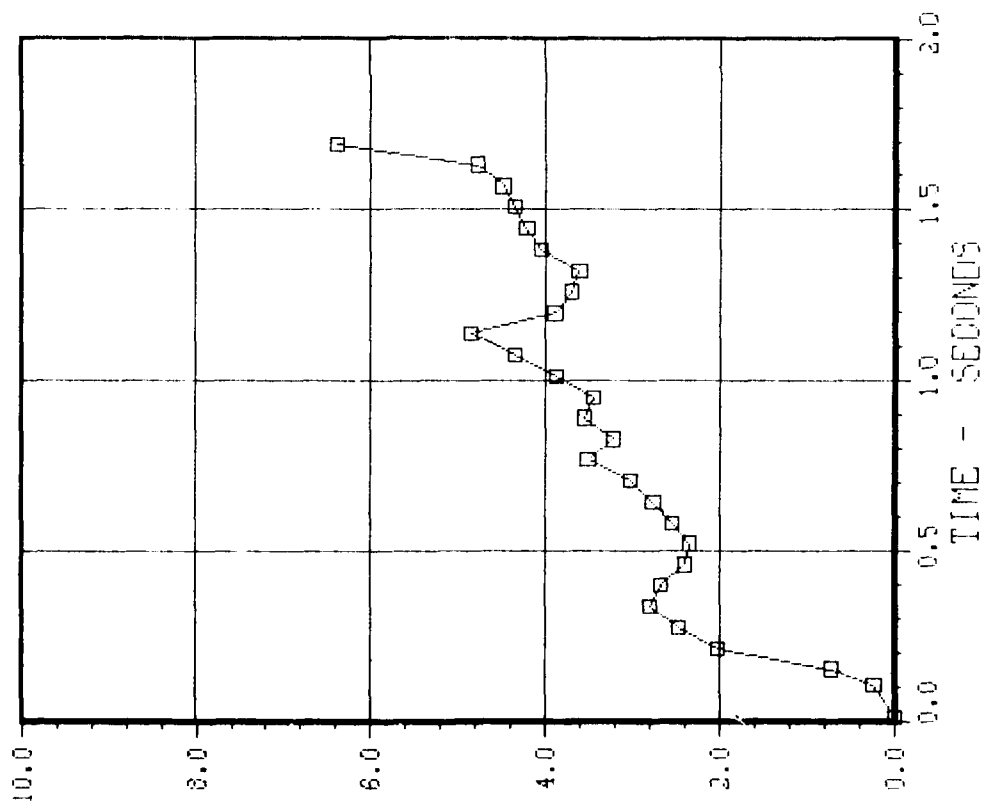


DUST RISE - EVENT ENCORE
 FIGURE 3.15 FILM 16558
 DISTANCE FROM GROUND ZERO 2350 FEET
 SHOCK ARRIVAL TIME 1.71 SECONDS
 PEAK PRESSURE 11.3 PSI
 THERMAL ENERGY 76 CAL/(CM)**2

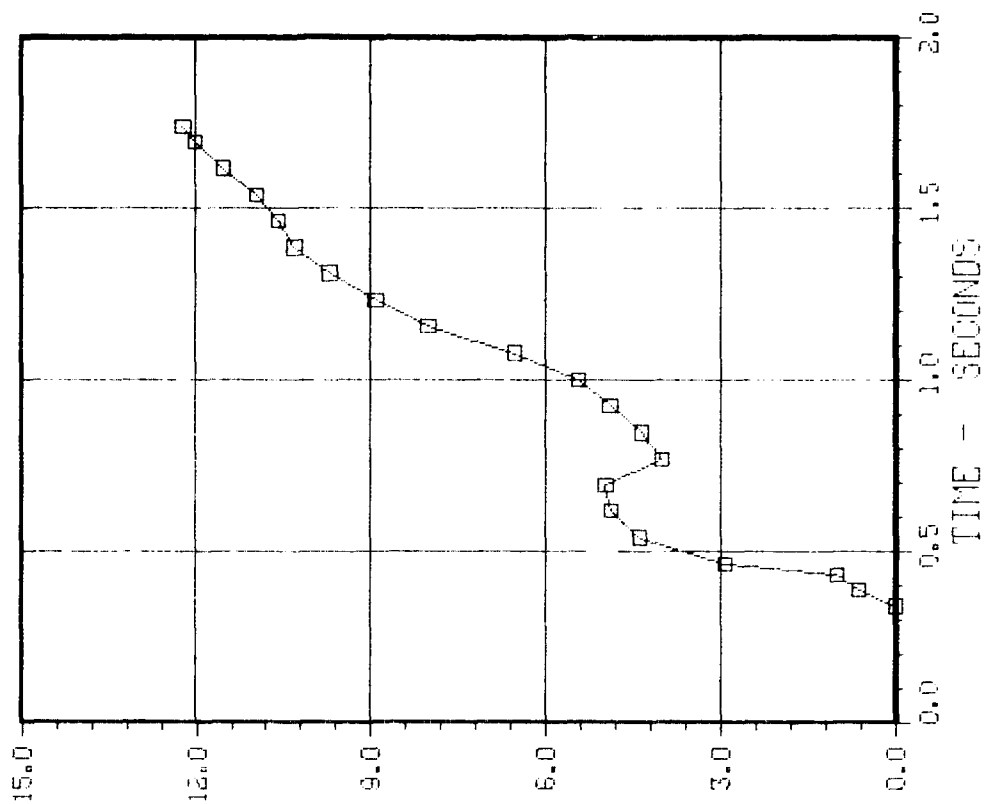


HEIGHT - FEET

DUST RISE - EVENT ENCORE
 FIGURE 3.16 FILM 16559
 DISTANCE FROM GROUND ZERO 2350 FEET
 SHOCK ARRIVAL TIME 1.71 SECONDS
 PEAK PRESSURE 11.3 PSI
 THERMAL ENERGY 76 CAL/(CM)**2

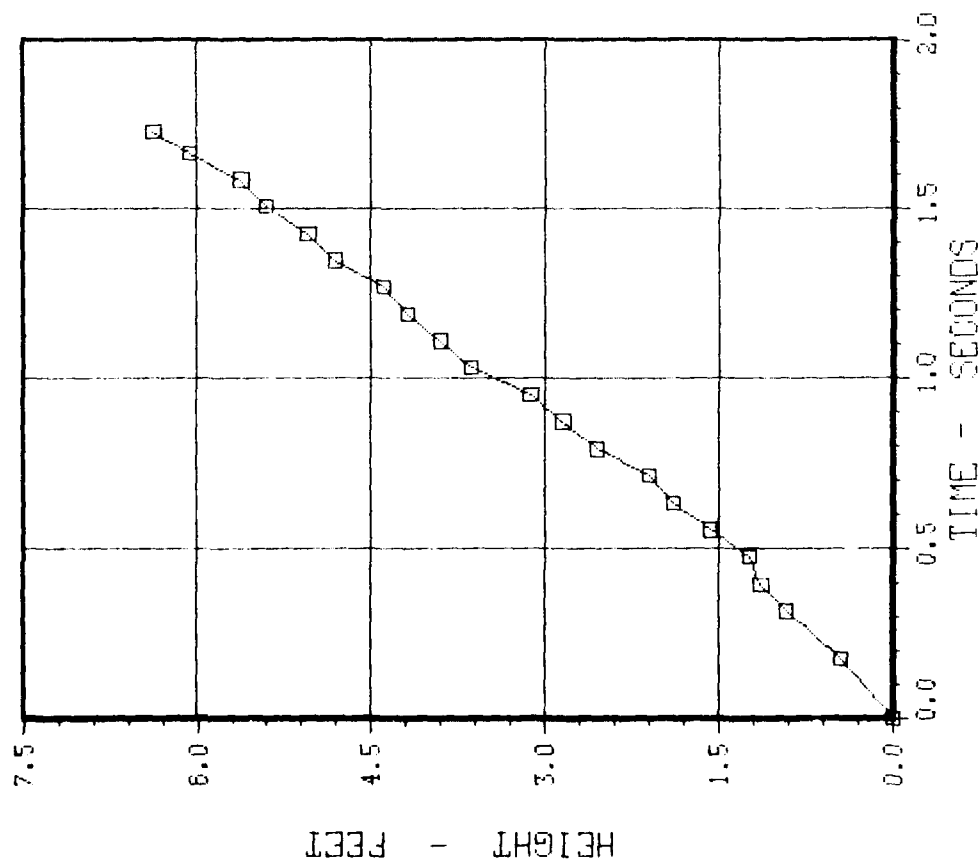


DUST RISE - EVENT ENCORE
 FIGURE 3.17 FILM 16679
 DISTANCE FROM GROUND ZERO 2440 FEET
 SHOCK ARRIVAL TIME 1.75 SECONDS
 PEAK PRESSURE 11.2 PSI
 THERMAL ENERGY 74 CAL/(CM)**2

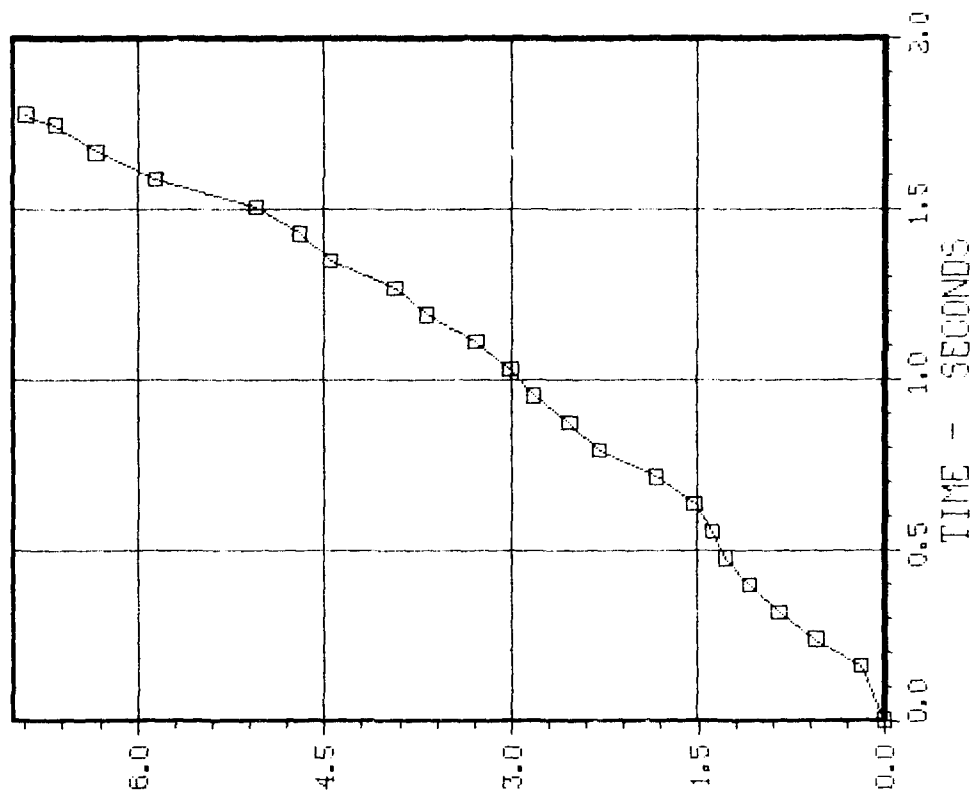


HEIGHT - FEET

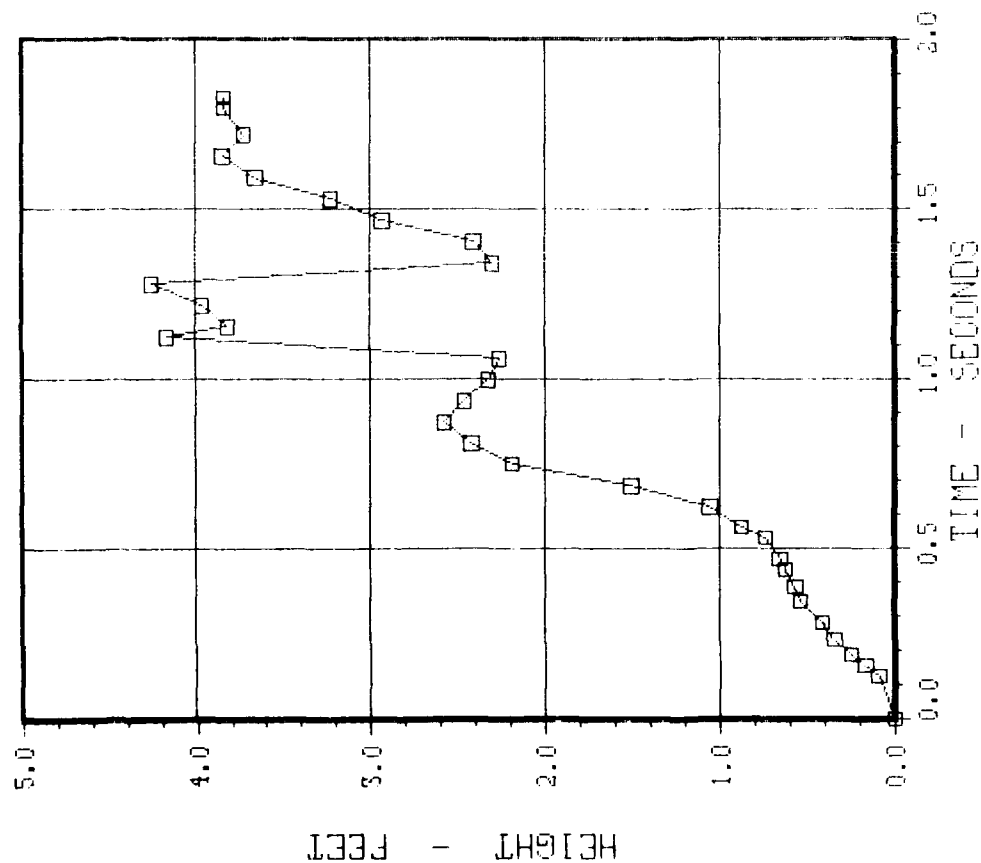
DUST RISE - EVENT ENCORE
 FIGURE 3.18 FILM 16540
 DISTANCE FROM GROUND ZERO 2474 FEET
 SHOCK ARRIVAL TIME 1.75 SECONDS
 PEAK PRESSURE 10.8 PSI
 THERMAL ENERGY 73 CAL/(CM)**2



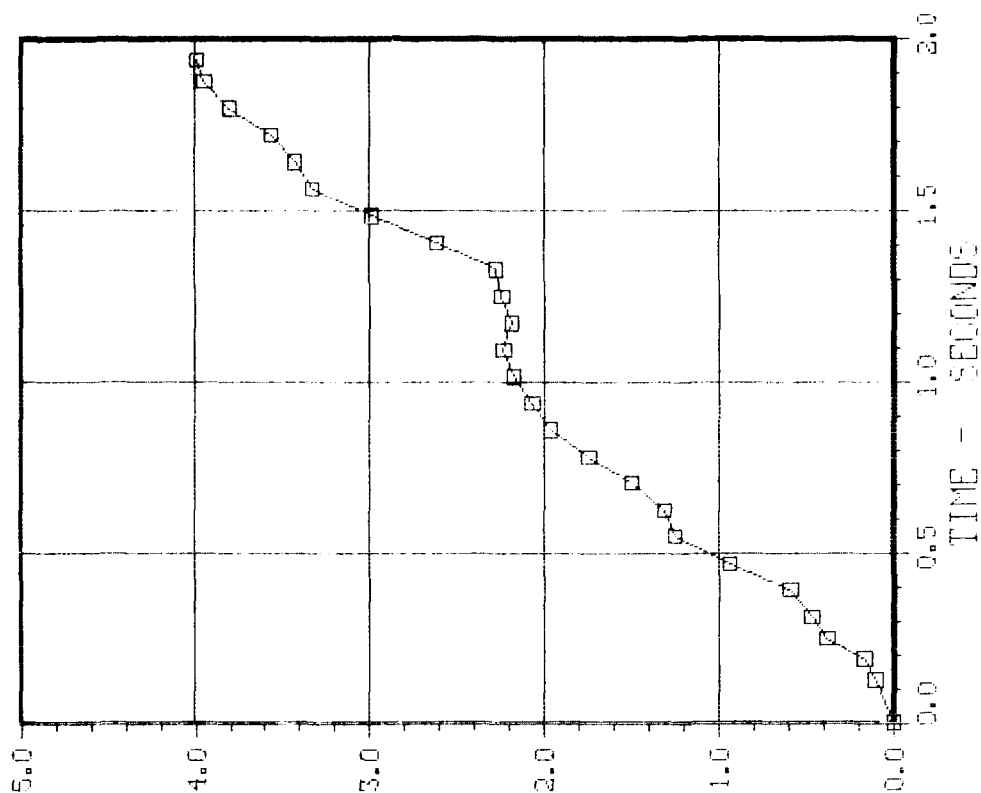
DUST RISE - EVENT ENCORE
 FIGURE 3.19 FILM 16541
 DISTANCE FROM GROUND ZERO 2474 FEET
 SHOCK ARRIVAL TIME 1.79 SECONDS
 PEAK PRESSURE 10.8 PSI
 THERMAL ENERGY 73 CAL/(CM)**2



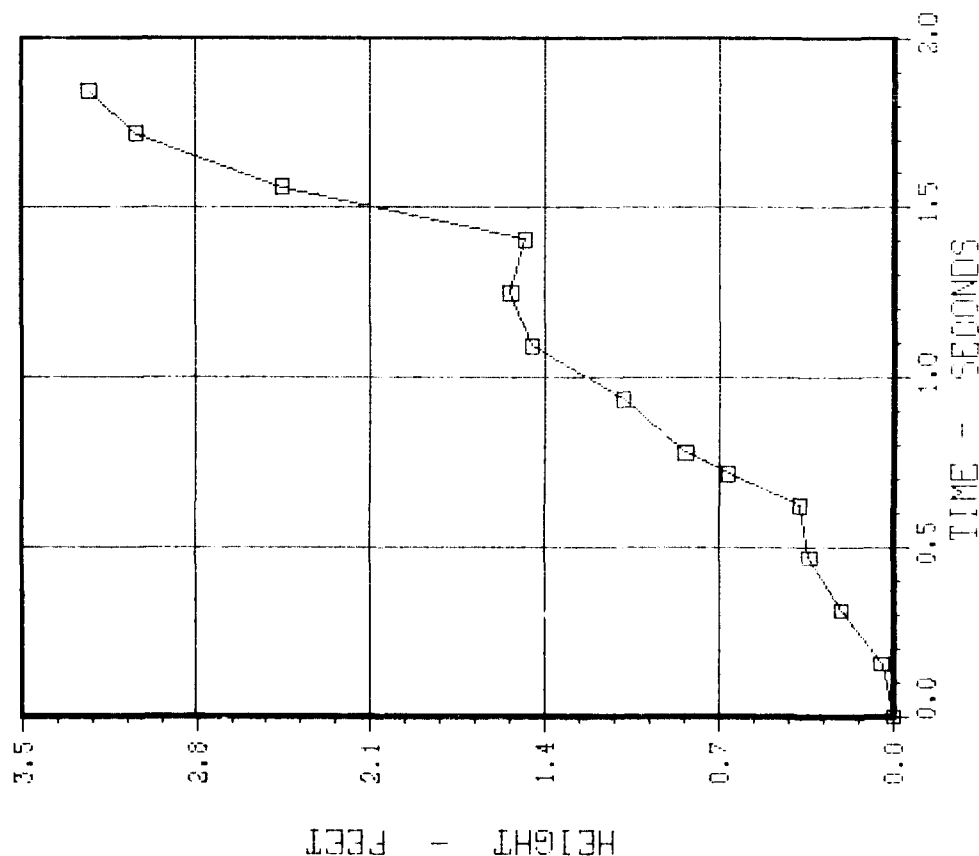
DUST RISE - EVENT ENCORE
 FIGURE 3.20 FILM 16693
 DISTANCE FROM GROUND ZERO 2610 FEET
 SHOCK ARRIVAL TIME 1.84 SECONDS
 PEAK PRESSURE 11.0 PSI
 THERMAL ENERGY 67 CAL/(CM)**2



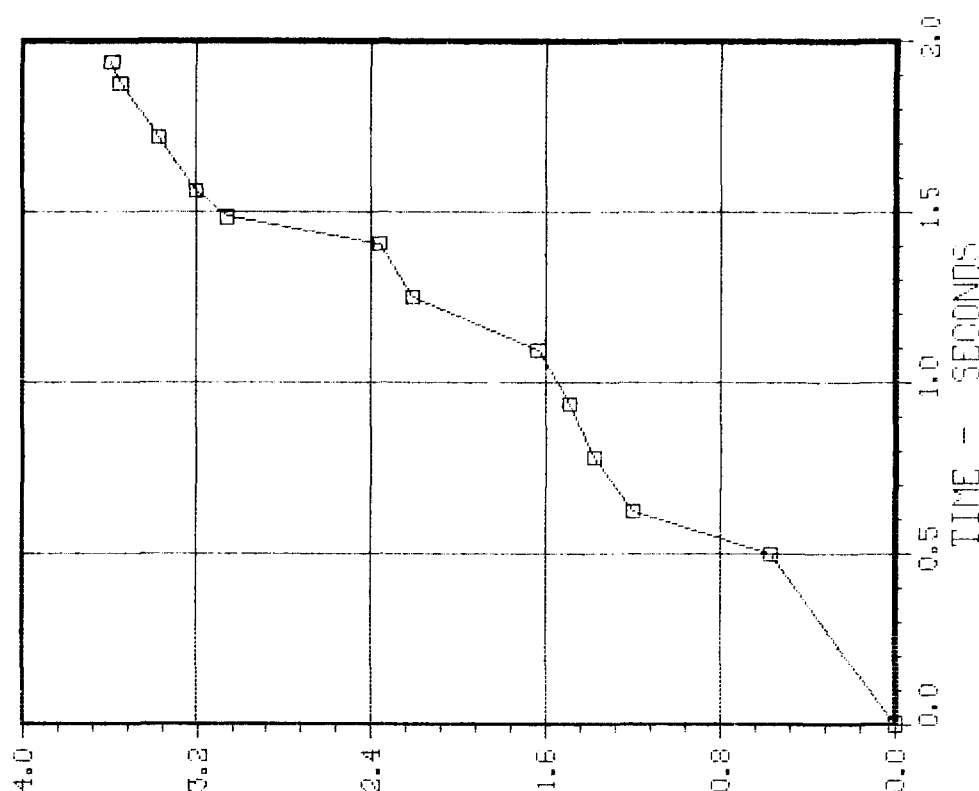
DUST RISE - EVENT ENCORE
 FIGURE 3.21 FILM 16694
 DISTANCE FROM GROUND ZERO 2610 FEET
 SHOCK ARRIVAL TIME 1.95 SECONDS
 PEAK PRESSURE 11.0 PSI
 THERMAL ENERGY 67 CAL/(CM)**2



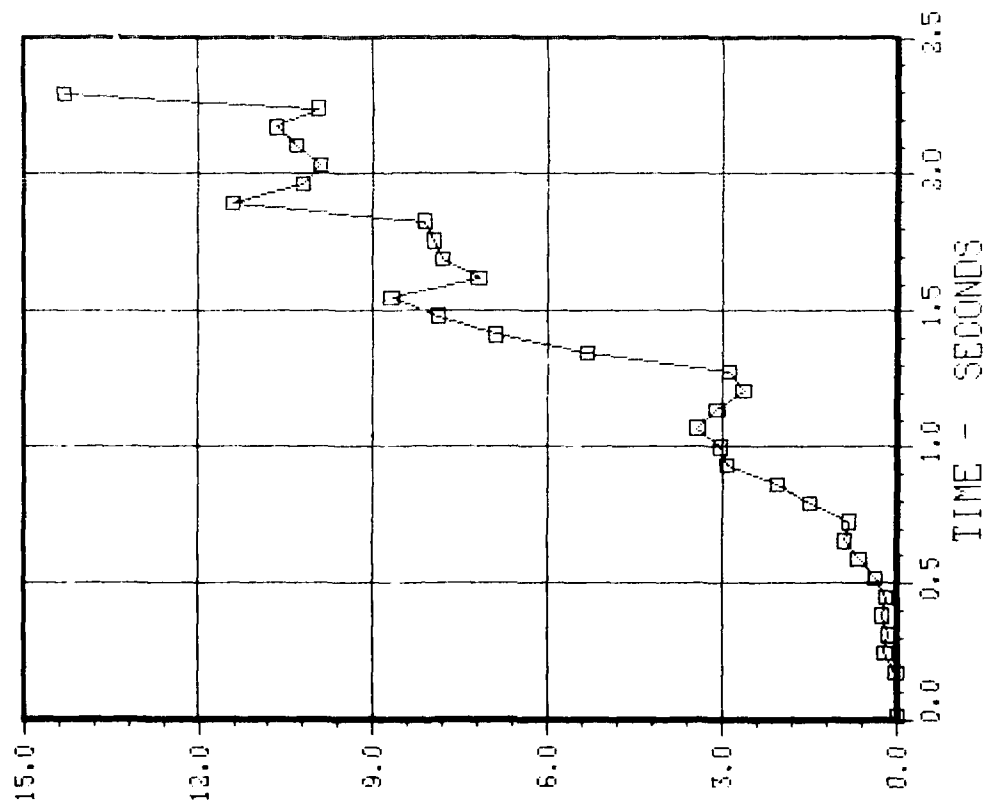
DUST RISE - EVENT ENDURE
 FIGURE 3.22 FILM 16595
 DISTANCE FROM GROUND ZERO 2610 FEET
 SHOCK ARRIVAL TIME 1.86 SECONDS
 PEAK PRESSURE 11.0 PSI
 THERMAL ENERGY 67 CAL/(CM)**2



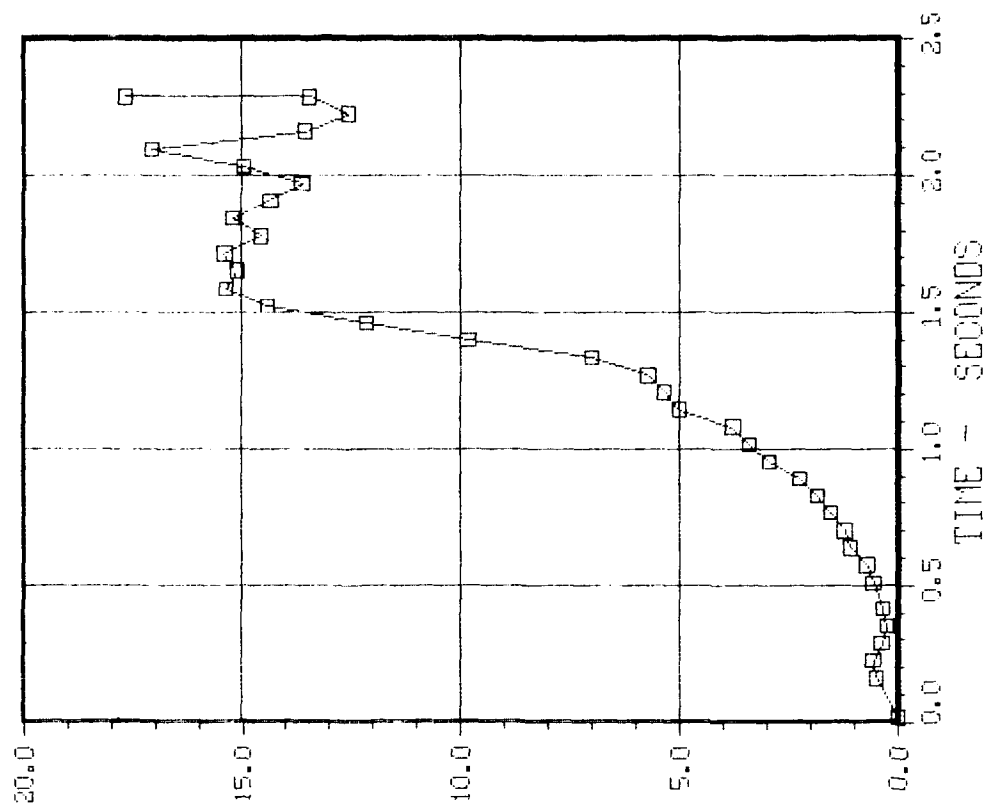
DUST RISE - EVENT ENDURE
 FIGURE 3.23 FILM 16596
 DISTANCE FROM GROUND ZERO 2610 FEET
 SHOCK ARRIVAL TIME 1.95 SECONDS
 PEAK PRESSURE 11.0 PSI
 THERMAL ENERGY 67 CAL/(CM)**2



DUST RISE - EVENT ENCORE
 FIGURE 3.24 FILM 16562
 DISTANCE FROM GROUND ZERO 3380 FEET
 SHOCK ARRIVAL TIME 2.29 SECONDS
 PEAK PRESSURE 9.50 PSI
 THERMAL ENERGY 51 CAL/(CM)**2

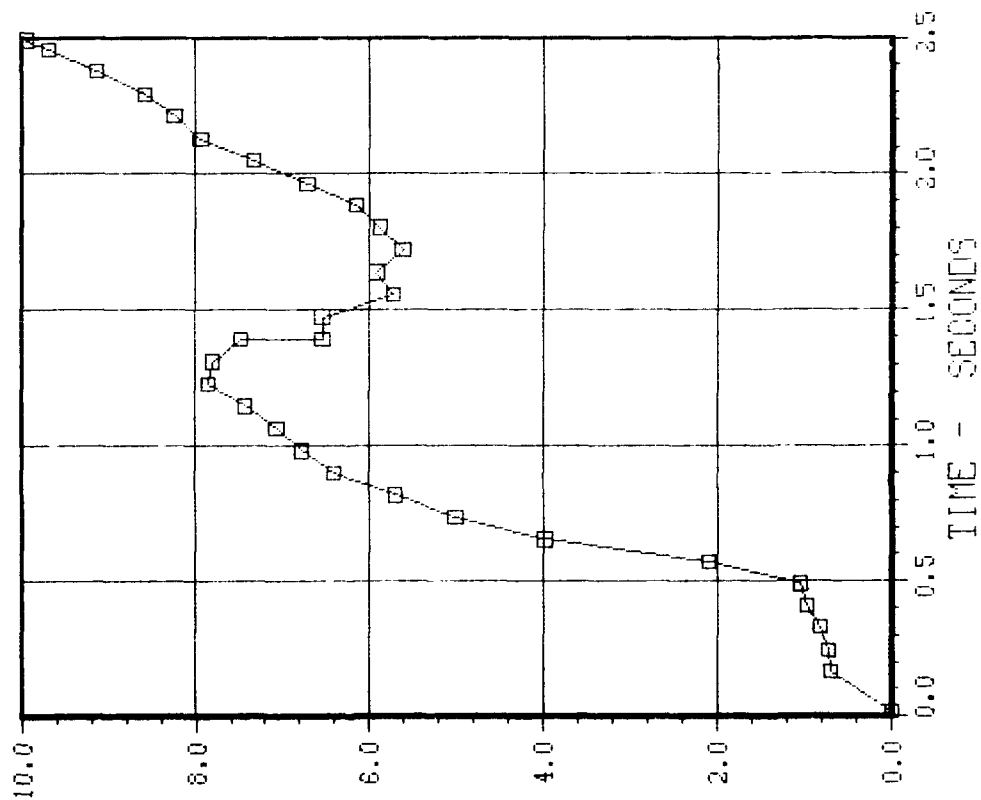


DUST RISE - EVENT ENCORE
 FIGURE 3.25 FILM 16563
 DISTANCE FROM GROUND ZERO 3380 FEET
 SHOCK ARRIVAL TIME 2.29 SECONDS
 PEAK PRESSURE 9.50 PSI
 THERMAL ENERGY 51 CAL/(CM)**2

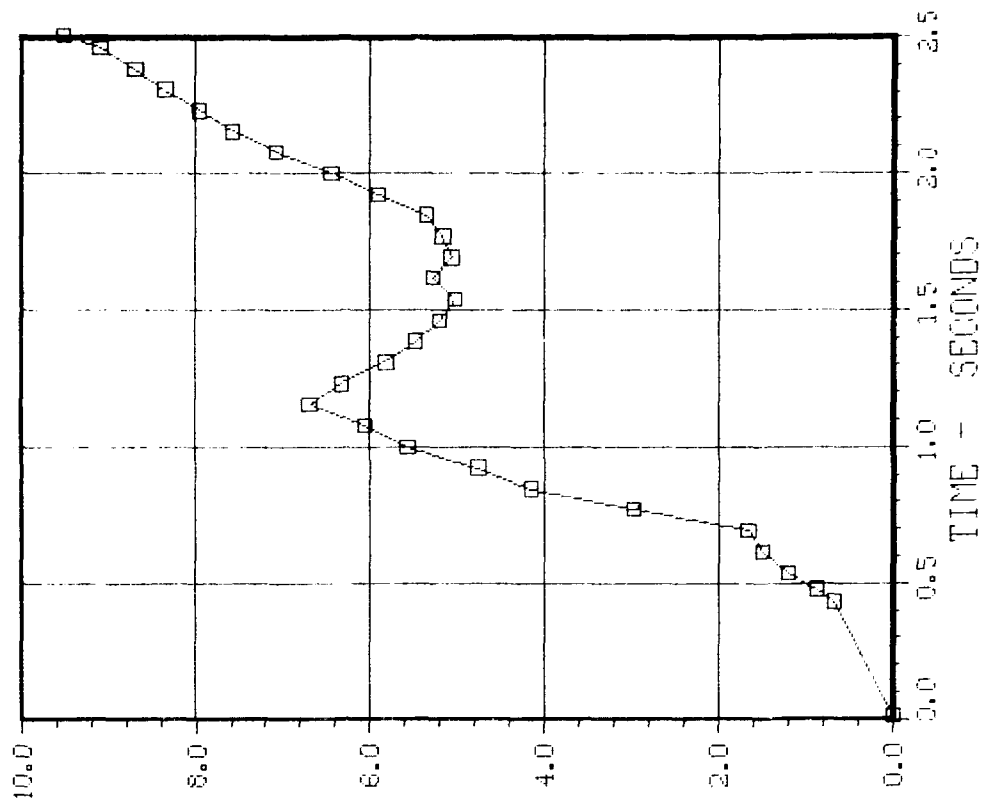


HEIGHT - FEET

DUST RISE - EVENT ENCORE
 FIGURE 3.26 FILM 16572
 DISTANCE FROM GROUND ZERO 3562 FEET
 SHOCK ARRIVAL TIME 2.51 SECONDS
 PEAK PRESSURE 9.00 PSI
 THERMAL ENERGY 47 CAL/(CM)**2

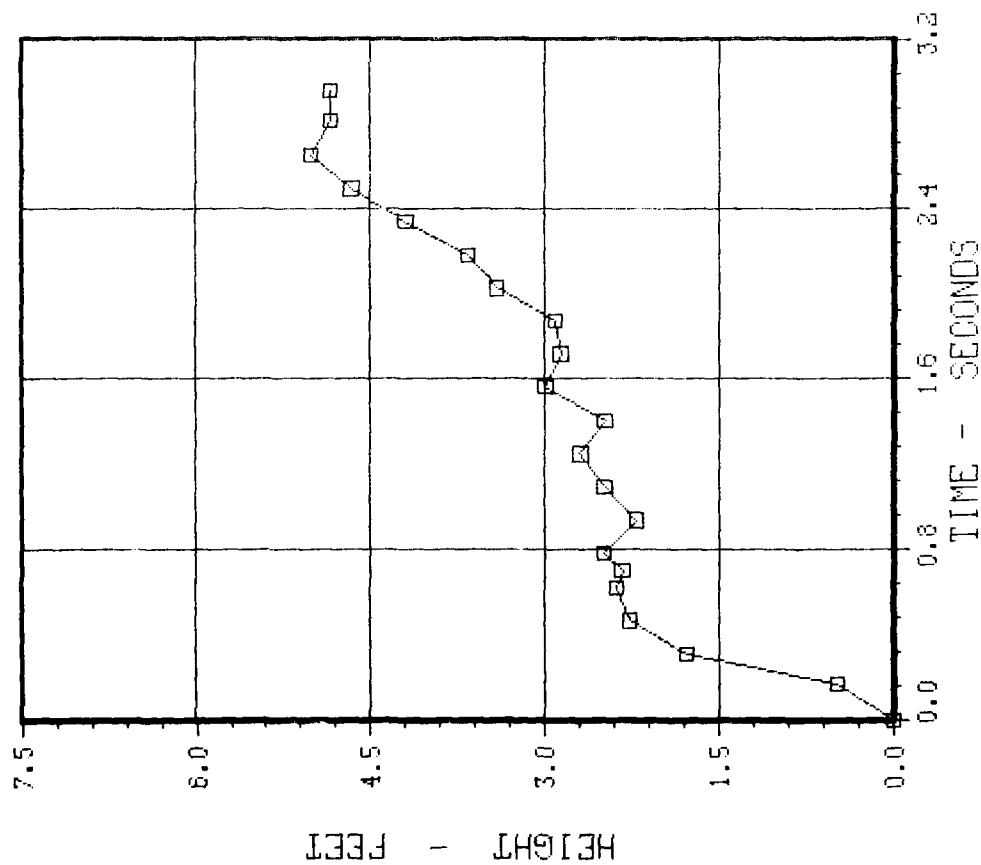


DUST RISE - EVENT ENCORE
 FIGURE 3.27 FILM 16573
 DISTANCE FROM GROUND ZERO 3562 FEET
 SHOCK ARRIVAL TIME 2.51 SECONDS
 PEAK PRESSURE 9.00 PSI
 THERMAL ENERGY 47 CAL/(CM)**2

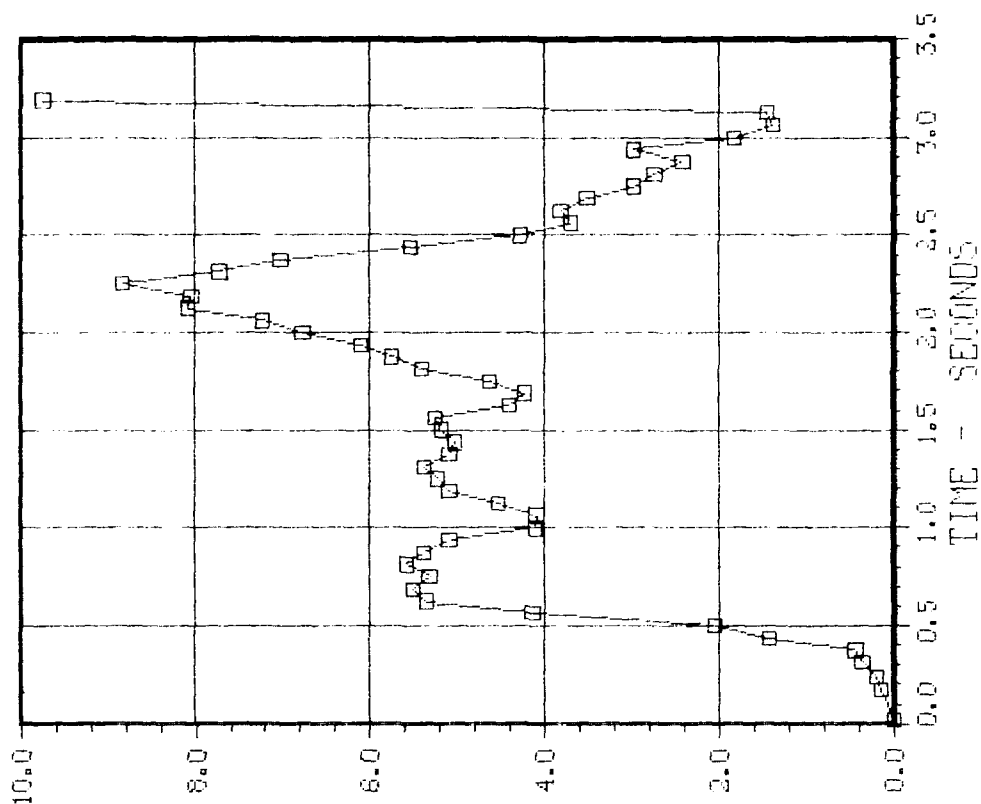


HEIGHT - FEET

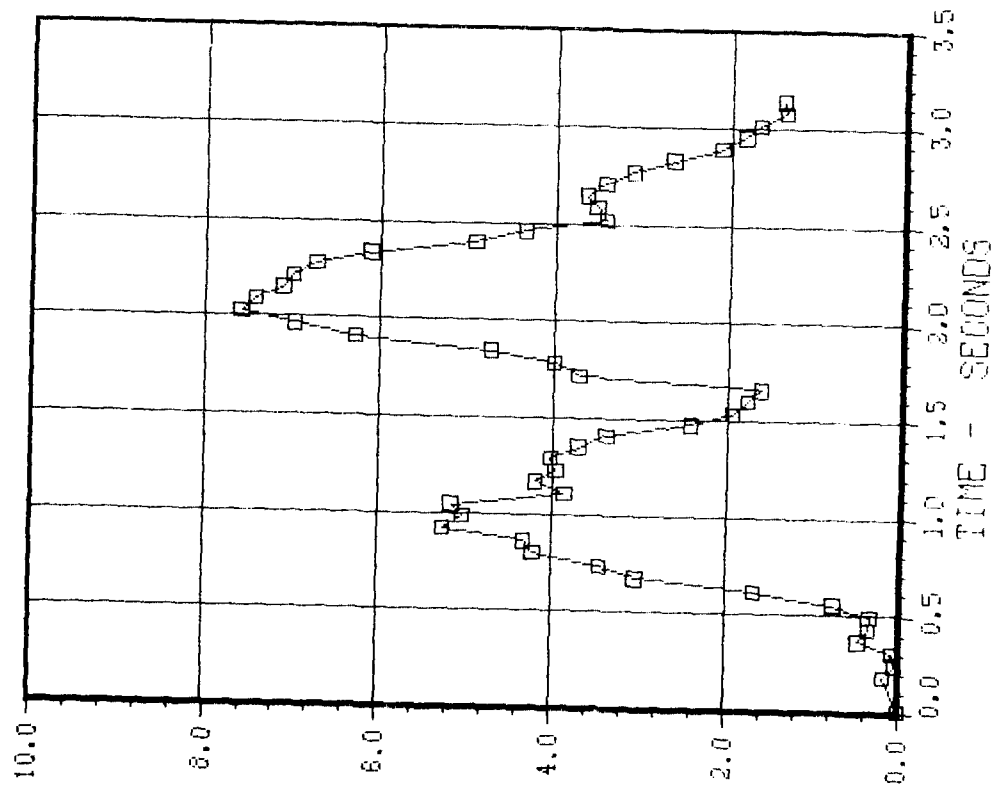
DUST RISE - EVENT ENCORE
 FIGURE 3.28 FILM 16542
 DISTANCE FROM GROUND ZERO 4345 FEET
 SHOCK ARRIVAL TIME 2.97 SECONDS
 PEAK PRESSURE 7.40 PSI
 THERMAL ENERGY 33 CAL/(CM)**2



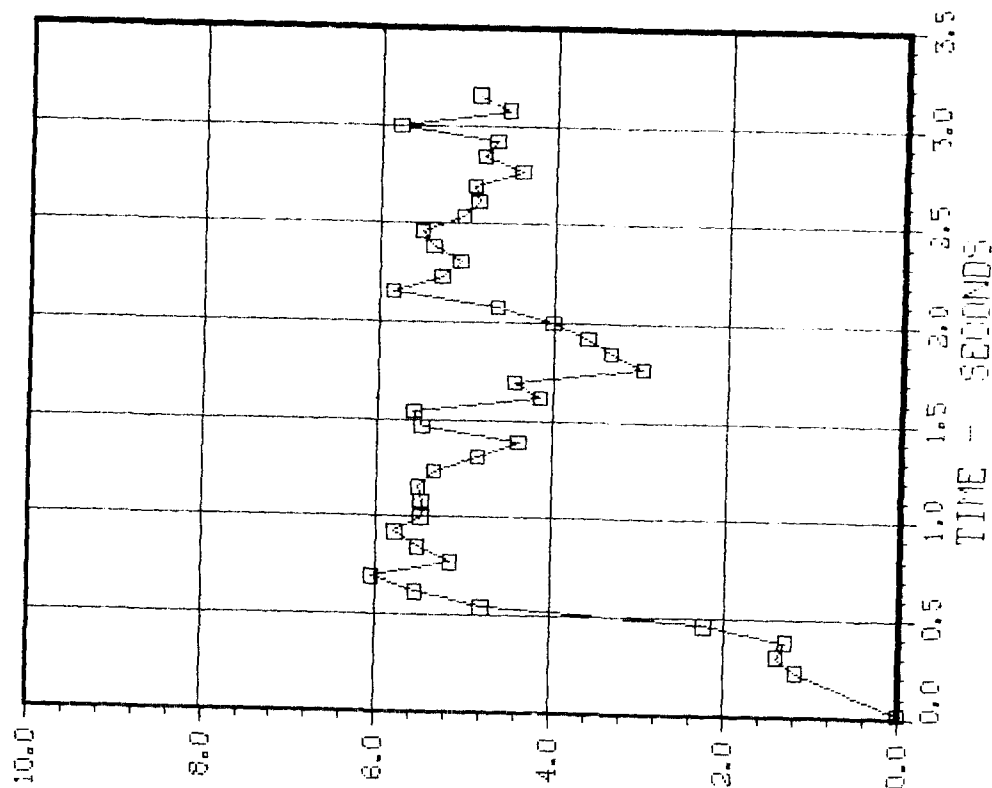
DUST RISE - EVENT ENCORE
 FIGURE 3.29 FILM 16568
 DISTANCE FROM GROUND ZERO 4550 FEET
 SHOCK ARRIVAL TIME 3.19 SECONDS
 PEAK PRESSURE 7.10 PSI
 THERMAL ENERGY 32 CAL/(CM)**2



DUST RISE - EVENT ENCORE
 FIGURE 3.30 FILM 16569
 DISTANCE FROM GROUND ZERO 4550 FEET
 SHOCK ARRIVAL TIME 3.17 SECONDS
 PEAK PRESSURE 7.10 PSI
 THERMAL ENERGY 32 CAL/(CM)**2

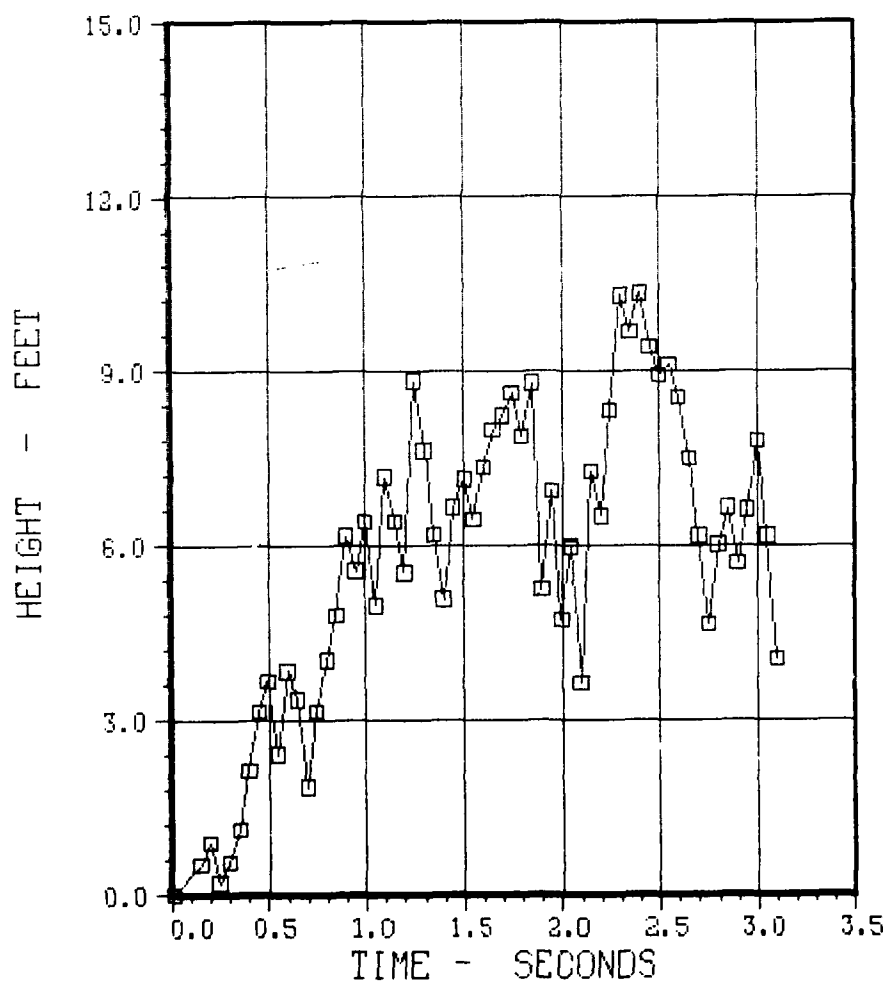


DUST RISE - EVENT ENCORE
 FIGURE 3.31 FILM 16570
 DISTANCE FROM GROUND ZERO 4590 FEET
 SHOCK ARRIVAL TIME 3.17 SECONDS
 PEAK PRESSURE 7.00 PSI
 THERMAL ENERGY 33 CAL/(CM)**2



HEIGHT - FEET

DUST RISE - EVENT ENCORE
FIGURE 3.32 FILM 16571
DISTANCE FROM GROUND ZERO 4590 FEET
SHOCK ARRIVAL TIME 3.14 SECONDS
PEAK PRESSURE 7.00 PSI
THERMAL ENERGY 33 CAL/(CM)**2



SECTION IV

SUMMARY AND RECOMMENDATIONS

This exploratory study shows that key information required for development and validation of reliable, near-surface, dusty thermal-layer models is available in photographic films of past nuclear tests. If time is of the essence, it could very well be that this approach of studying what has been recorded in past nuclear test films will arrive at the needed information for the MX precursor environment sooner than other currently-pursued, experimental programs.

Without doubt, more study is necessary of the (1) available information, and (2) techniques of retrieving that information. For example, the near-surface, horizontal drifts must be included into any thermal model, since they can affect the local environment. Although such horizontal velocities were observed, time did not allow for precise measurements to be made.

Most important is the need for a planned, interrelated program which will permit correlation between measurements and computed results. For example, as shown in Section II, Event CLIMAX allows measurement of the near-surface spatial position of the breakaway, reflected, and precursor shocks as a function of time before Mach stem formation. Comparison of improved and additional measurements with HULL results, would allow understanding of the ability of the current thermal model to reproduce real data near the surface. Comparisons of a family of computer runs could guide the development of the required, near-surface model.

It should be remembered that some of the best measurements of the time history of the nuclear-thermal pulse have been determined from photographic records. The techniques are well-known⁷. As a result, the determination (through calculations) of the thermal flux and fluence at a distant point can be easily established, since atmospheric transmission measurements are also available. Thus, nuclear thermal data and cloud puff measurements will serve as a key input to the current development of the thermal dust layer models now in progress at LASL⁶.

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7. DNA 4132F, "Empirical SBM Data From Nuclear Detonation Photography", W.F. Dudziak, et. al., Information Science, Inc., 1976.

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